Black Sea Journal of Agriculture

Volume 8 | Issue 2

ISSN: 2618 - 6578

BS Journals

BLACK SEA JOURNAL OF AGRICULTURE

(BSJ AGRI)

BS Journals

Black Sea Journal of Agriculture (BSJ Agri) is a double-blind peer-reviewed, open-access international journal published electronically 6 times (January, March, May, July, September, and November) in a year since January 2018. It publishes, in English, full-length original research articles, innovative papers, conference papers, reviews, mini-reviews, rapid communications or technical note on various aspects of agricultural science like agricultural economics, agricultural engineering, animal science, agronomy, including plant science, theoretical production ecology, horticulture, plant breeding, plant fertilization, plant protect and soil science, aquaculture, biological engineering, including genetic engineering and microbiology, environmental impacts of agriculture and forestry, food science, husbandry, irrigation and water management, land use, waste management etc.

ISSN: 2618 - 6578

Phone: +90 362 408 25 15

Fax: +90 362 408 25 15

Email: bsjagri@blackseapublishers.com

Web site: http://dergipark.gov.tr/bsagriculture

Sort of publication: Periodically 6 times (January, March, May, July, September, and November) in a year

Publication date and place: March 15, 2025- Samsun, TÜRKİYE

Publishing kind: Electronically

REVIEWERS OF THE ISSUE*

Prof. Dr. Ali Cesur ONMAZ, Erciyes University, Veterinary Sciences, Veterinary Internal Medicine, TÜRKİYE

Prof. Dr. Bilge BAHAR, Gümüşhane University, Department of Field Crops, Cereals and Legumes, TÜRKİYE

Prof. Dr. Daniel ZABORSKI, West Pomeranian University of Technology, Department of Ruminants Science, Biometry, POLAND

Prof. Dr. Hanife MUT, Bilecik Şeyh Edebali University, Department of Field Crops, Pasture-Meadow Forage Plants, TÜRKİYE

Prof. Dr. Harun KAMAN, Akdeniz University, Department of Agricultural Structures and Irrigation, Irrigation, TÜRKİYE

Prof. Dr. Hayrettin KUŞÇU, Bursa Uludağ University, Department of Biosystems Engineering, Irrigation, TÜRKİYE

Prof. Dr. İlker Hüseyin ÇELEN, Tekirdağ Namik Kemal University, Department of Biosystems Engineering, Agricultural Machines, TÜRKİYE

Prof. Dr. İsmet BOZ, United Arab Emirates University, Department of Integrative Agriculture, Agricultural Marketing, UAE

Prof. Dr. Mohamed IBRAHIM, Cairo University, Department of Agricultural Engineering, Agricultural Engineering, EGYPT

Prof. Dr. Osman GÖKDOĞAN, Isparta Applied Sciences University, Department of Agricultural Machinery and Technologies Engineering, Agricultural Machines, TÜRKİYE

Prof. Dr. Süleyman KARAMAN, Akdeniz University, Department of Agricultural Economics, Econometric and Statistical Methods, TÜRKİYE

Prof. Dr. Taki DEMİR, Sakarya Applied Sciences University, Department of Horticulture, Pomology and Treatment, TÜRKİYE

Prof. Dr. Tanzer ERYILMAZ, Yozgat Bozok University, Department of Agricultural Machinery and Technologies Engineering, Agricultural Machine Systems, TÜRKİYE

Prof. Dr. Vecdi DEMİRCAN, Isparta Applied Sciences University, Department of Agricultural Economics, Marketing in Agricultural Management, TÜRKİYE

Assoc. Prof. Dr. Ece Börteçine KASAPOĞLU ULUDAMAR, Çukurova University, Department of Plant Protection, Entomology, TÜRKİYE

Assoc. Prof. Dr. Erdal ÇAÇAN, Bingöl University, Department of Field Crops, Pasture-Meadow Forage Plants, TÜRKİYE

Assoc. Prof. Dr. Erhan GÖÇMEN, Tekirdağ Namik Kemal University, Department of Biosystems Engineering, Irrigation Systems, TÜRKİYE

Assoc. Prof. Dr. Gülten EMEK TUNA, Aydın Adnan Menderes University, Veterinary Sciences, Veterinary Medicine, TÜRKİYE

Volume 8, Issue 2 (2025)

Table of Contents

Research Articles

Black Sea Journal of Agriculture
doi: 10.47115/bsagriculture.1509293

Open Access Journal
e-ISSN: 2618 – 6578

Research Article
Volume 8 - Issue 2 : 124-133 / March 2025

THE EFFECT OF NaCl-SALINITY APPLICATIONS ON THE IMPROVEMENT OF QUALITY CHARACTERISTICS AND YIELD OF TOMATO (*Lycopersicon esculentum* L.) GROWN IN SUBSTRATE CULTURE

Güney AKINOĞLU[1]*, Ahmet KORKMAZ[1], Salih DEMİRKAYA[1], Songül RAKICIOĞLU[1], Zerrin CİVELEK[1]

[1]*Ondokuz Mayıs University, Agricultural Faculty, Department of Soil Science and Plant Nutrition, 55137, Samsun, Türkiye*

Abstract: Salt application in soilless cultivation systems can be considered as a strategic tool to improve tomato fruit quality. In this context, the effects of increasing the salt concentration in the nutrient solution added to the solid culture medium on yield and yield components, biophysical and organoleptic quality traits of tomato (*Lycopersicon esculentum* L. cv. Kardelen F1) under greenhouse conditions were studied. The salt in the nutrient solution was applied to tomato plants as sodium chloride (NaCl) at four concentrations (0, 14.1, 44.4, and 70.4 mM). Each pot received 150 mL of nutrient solution daily during the vegetative period, while 300 mL was applied daily after flowering. This study was conducted with three replicates following a randomized block design. Plants were harvested 90 days after transplanting. Low salt application in the nutrient solution (14.1 mM NaCl) increased total fruit yield, while the high salt application did not effect fruit yield compared to the control. Salt application at increasing concentrations decreased fruit size and diameter but increased the dry matter in the fruit. The salt treatment mainly positively affected the commercial and organoleptic quality parameters of the tomato fruits. In conclusion, a low level of sodium chloride (14.1 mM NaCl) in soilless culture enhanced fruit production, while moderate (44.4 mM) and high (70.4 mM) concentrations improved various fruit quality traits.

Keywords: *Lycopersicon esculentum*, Substrate culture, NaCl, Yield, Organoleptic and biophysical quality

***Corresponding author:** Ondokuz Mayıs University, Agricultural Faculty, Department of Soil Science and Plant Nutrition, 55137, Samsun, Türkiye
E mail: guney_akinoglu@ymail.com (G. AKINOĞLU)
Güney AKINOĞLU https://orcid.org/0000-0002-4169-8412
Ahmet KORKMAZ https://orcid.org/0000-0001-5595-0618
Salih DEMİRKAYA https://orcid.org/ 0000-0002-7374-0160
Songül RAKICIOĞLU https://orcid.org/0000-0002-8013-6439
Zerrin CİVELEK https://orcid.org/0000-0002-2824-116X

Received: July 2, 2024
Accepted: November 17, 2024
Published: March 15, 2025

Cite as: Akınoğlu G, Korkmaz A, Demirkaya S, Rakıcıoğlu S, Civelek Z. 2025. The effect of NaCl-salinity applications on the improvement of quality characteristics and yield of tomato (*Lycopersicon Esculentum* L.) grown in substrate culture. BSJ Agri, 8(2): 124-133.

1. Introduction

Currently, soilless cultivation is gaining popularity as a new type of intensive and efficient technology (Lucke et al., 2019). Soilless cultivation is a method of growing plants that does not use soil as a rooting medium. It is widely used to improve the regulation of environmental conditions for growth and to avoid soil ambiguity (Tzortzakis et al., 2020). The techniques of solid substrate culture can be divided into the hanging bag technique, the grow bag technique, the trench or trough technique and the pot technique. These techniques require solid substrates. The chosen medium must be flexible, friable, water and air retentive and easy to drain. It must also be free of toxic substances, pests, pathogenic microorganisms and nematodes (Fussy and Papenbrock, 2022). The plants are grown in a substrate with a continual supply of nutrient solution, allowing for optimal mineral nutrition management (Lu et al., 2022). Commercially, substrate culture has been used successfully for fruiting vegetables (Tüzel et al., 2019).

Tomato is a popular vegetable grown on large areas around the world and has a high production potential compared to other vegetables (Nangare et al., 2016; Cui et al., 2019). Tomato fruit contains many phytochemical compounds that can improve human health (Talens et al., 2016). This fruit is an important dietary source of lycopene, potassium, iron, folic acid and vitamin C (Alsuhaibani, 2018; Rana et al., 2019; Gonçalves et al., 2020; Wu et al., 2022). In addition, tomatoes provide other antioxidants such as β-carotene and phenolic compounds such as flavonoids (Tomas et al., 2017; Botella et al., 2021; Izzo et al., 2022).

Consumers are becoming more aware of the quality of fruit and vegetables and are demanding higher quality in the products they buy (Mascarello et al., 2015; Petrescu et al., 2019; Alam et al., 2021). The quality of a fresh food product includes characteristics such as colour, texture, taste and health-promoting compounds, but can also include undesirable characteristics such as possible damage or spoilage (Amit et al., 2017; Sajdakowska et al., 2018). Although all these intrinsic attributes are included in the definition of quality, most breeding studies and efforts have been aimed mainly at improving and maintaining external quality for many years. Selection for yield, size, colour, and shelf life can have unintended negative effects on fruit quality (Zhang et al., 2016; Lara et al., 2019; Thole et al., 2020).

Plants are exposed to various stress factors throughout their life cycle (Mareri et al., 2022). Excessive salinity is one of the most critical environmental stressors that drastically affects the growth, nutrition and productivity of many plant species (Shrivastava and Kumar, 2015; Ma et al., 2020). The response of plants to salinity is complex and involves physiological and biochemical processes as well as morphological and developmental changes (Arif et al., 2020). On the other hand, the use of controlled abiotic stress could be an interesting approach to improving the nutraceutical value of fruits and vegetables (Toscano et al., 2019). In addition, increasing the EC of the nutrient solution is used to improve fruit quality when growing tomatoes with soilless cultivation techniques. This is done either; by increasing the amount of fertilizer added to the nutrient solution or by adding sodium chloride (NaCl) salt to the nutrient solution. The second way is preferred because it is cheaper (Gül, 2012). Cultural management provides excellent possibilities to obtain the high nutritional and organoleptic quality of fresh tomato fruits (Bertin and Génard, 2018; Coyago-Cruz et al., 2018; Asensio et al., 2019; Lima et al., 2022). In addition, the nutritional and organoleptic quality of fresh tomatoes can be influenced by many pre- and postharvest factors, such as genetic characteristics, growing conditions, stage of maturity at harvest and crop management (Arah et al., 2015; Iglesias et al., 2015; Urrestarazu et al., 2015; Distefano et al., 2022).

Although there are negative effects, an increase in the total salt concentration in the root zone of tomatoes is a factor that affects fruit quality as well as individual nutrients (Zhang et al., 2016). Increasing root zone salinity in moderate levels improves tomato fruit quality (Krauss et al., 2006). Improvements in fruit quality with salinity have been found to be related to increases in the content of sugars, organic acids, and amino acids in fruit (Rodríguez et al. 2019; Ávalos-Sánchez et al., 2022). Other studies have reported that red fruit colour and shelf life increase with salinity (Sonneveld and Van Der Burg, 1991; Botella et al., 2000). In addition to these, an increase in the total salt concentration in the nutrient solution increased the concentration of vitamin C, lycopene, and β-carotene (Tzortzakis et al., 2022).

The tomato is generally considered a moderately salt-tolerant plant (Ladewig et al., 2021). The maximum yield for tomato plants grown in substrate is achieved at an electrical conductivity value (EC) of 2.5 to 2.9 $dS \cdot m^{-1}$ (Sonneveld and Van Der Burg, 1991). Furthermore, Sonneveld and Straver (1994) reported that salt should be added to the nutrient solution to increase the EC value to 3.5–3.7 $dS \cdot m^{-1}$ for tomato plants.

Most cultivation practices have been used to optimize crop characteristics and yield, but little attention has been paid to the impact on fruit quality (Sánchez-González et al., 2016). Moreover, there is little information on the effects of increased salt concentration in the nutrient solution on plants in soilless cultivation (Moya et al., 2017). In soilless agriculture, elevated EC values in nutrient solutions are generally linked to adverse effects on plant growth and development as a result of increased salinity stress. However, this study highlights the beneficial role of controlled salinity achieved through the application of sodium chloride (NaCl). Therefore, we aimed to investigate the effects of increasing doses of sodium chloride in the nutrient solution on the yield and fruit quality of tomato plants grown in substrate culture.

2. Materials and Methods

Tomato (*Lycopersicon esculentum* L. cv. Kardelen F_1) was used as plant material. Seedlings were produced in a commercial nursery located in Antalya (Türkiye).

The tomato seedlings, which were approximately four inches tall and with their second pair of leaves, were planted singly in pots on 07/07/2022. The pots were placed in the greenhouse of Ondokuz Mayıs University in Türkiye under controlled conditions with a diurnal temperature of 28/21ºC and a relative humidity of 55±5%.

In the experiment, peat and perlite were mixed at the ratio of 2:1 (v/v) for the growth medium. Peat moss (Klasmann) is a moss that belongs to the genus of peat moss (Sphagnum) and has a high water-holding capacity and a pH value between 5.5 and 6.0. The expanded mineral perlite is an inert, salt-free substrate with a neutral pH and a high aeration capacity. One thousand and five hundred grams (1500 g) of the medium was put in each pot of 3 L capacity, 16.5 cm diameter and 19.0 cm depth. Holes were made at the bottom of the pots for drainage.

The experiment was set up in a randomized plot design with three replications by increasing the concentrations of NaCl (0, 14.1, 44.4 and 70.4 mM) in the nutrient solution (Korkmaz et al., 2018). The macroelement and microelement levels in the nutrient solution for the tomato plants (Kardelen F_1 variety) were applied according to the methods of Alpaslan et al. (1998). Calcium nitrate tetrahydrate ($Ca(NO_3)_2 \cdot 4H_2O$), potassium dihydrogen phosphate (KH_2PO_4), ammonium nitrate (NH_4NO_3), potassium nitrate (KNO_3), magnesium sulfate heptahydrate ($MgSO_4 \cdot 7H_2O$), magnesium nitrate hexahydrate ($Mg(NO_3)_2 \cdot 6H_2O$), manganese chloride dihydrate ($MnCl_2 \cdot 2H_2O$), boric acid (H_3BO_3), zinc sulfate heptahydrate ($ZnSO_4 \cdot 7H_2O$), copper sulfate pentahydrate ($CuSO_4 \cdot 5H_2O$), ammonium molybdate tetrahydrate (($(NH_4)_6Mo_7O_{27} \cdot 4H_2O$)) and iron (Fe)-EDDHA (ethylenediamine-N,N′-bis(2 hydroxyphenylacetic acid)) were used to prepare a nutrient solution at 12.0 mM nitrate (NO_3^-), 1.25 mM dihydrogen phosphate ($H_2PO_4^-$), 0.5 mM ammonium (NH_4^+), 5.25 mM potassium (K^+), 2.75 mM calcium (Ca^{2+}), 1.125 mM magnesium (Mg^{2+}), 0.125 mM sulfate (SO_4^{-2}), 40 µM iron (Fe), 5 µM manganese

(Mn), 30 µM boron (B), 0.75 µM copper (Cu), 4 µM zinc (Zn) and 0.5 µM molybdenum (Mo). The pH of the plant nutrient solution was adjusted to 5.5 with 1.0 M KOH or H_2SO_4 solution. All of the reagents used were of analytical grade.

The application of 150 mL of nutrient solution per day to each pot started at planting and continued until 14/08/2022. After that date, 300 mL of nutrient solution was applied per day to each pot until harvesting finished. The nutrient solutions were applied in the early morning hours. During the experiment, the moisture content of the pots was maintained around field capacity by controlling the drainage of irrigation. The pots were irrigated with tap water twice a day, in the afternoon and in the evening. The trial lasted 90 days.

2.1. Measurements

The fruit yield was measured in the lab using a sensitive scale (Precisa, XB-620M, Switzerland). The fruit yield was calculated for each plant as the cumulative fruit weight and the number of fruits during the six pickings, and then the average fruit weight was calculated. The dry matter content (%) was determined gravimetrically by drying 5 g of tomato homogenate in a laboratory oven (Nüve, ES-500, Türkiye) set at 70 °C until a constant weight was reached.

The diameter and height of the intact fruits were measured using a digital caliper (ASIMETO, Series 307). Fruit height was measured from the blossom end to the top of the fruit, and the diameter was taken as the maximum diameter of the equatorial section. Fruit shape index was calculated as vertical diameter divided by horizontal diameter. Every hour, the caliper was washed with water to remove deposited plant parts.

A digital penetrometer (PCE Instruments, PCE-FM 200) with a cone-shaped probe of Φ8 mm was used for firmness measurements in the equatorial zone. The resistance at penetration of the probe was measured and expressed in kgf cm^{-2}.

Colour measurements were taken using a portable colourimeter (CR-300, Konica Minolta, Tokyo, Japan) and data reported as lightness (L*), green to red (a*) and blue to yellow (b*) values of the CIELAB scale (Mcguire, 1992). Eeach record was an average of three measurements on every ripe tomato fruit (one at the distal area and two in the equatorial zone). Chroma [$C = (a^{*2}+b^{*2})^{1/2}$] and hue angle [h°=arctan (b*/a*)] were calculated from a* and b* values (Lancaster et al., 1997). Moreover, the results were combined as the Tomato Color Index (Hobson et al., 1983) by using equation 1.

$$\text{Tomato Color Index (TCI)} = \frac{(2000 \times a^*)}{(L^* \times \mathrm{C})} \qquad (1)$$

2.2. Sampling

Immediately after collection, fully ripened tomato fruits of each replicate were washed in tap water, blotted with a paper towel and halved. The seeds were removed and the pericarp and mesocarp were ground to a homogeneous puree in a blender (MB450, Türkiye) for about 2 minutes. Part of the sample was immediately used for some analyses (soluble solids content, titratable acidity, ascorbic acid, lycopene). In addition, the strained juice was filtered with a 120 mm paper filter (Whatman). The clearly filtered juice was used for the pH and EC analyses.

2.3. Analytical Methods

Electrical conductivity (EC) was determined using a conductivity meter (Mettler Toledo Instruments, FiveEasy Plus Cond meter FP30) and expressed in dS/m; pH was determined using a pH meter (Mettler Toledo Instruments, SevenCompact pH meter S220) (AOAC, 1990).

To determine the titratable acidity (TA), 10 mL of filtered tomato juice was titrated with 0.1 N standardized sodium hydroxide (NaOH) solution until equilibrium (pH of 8.1) and the measured TA was expressed as the concentration (%) of citric acid, a major organic acid in tomatoes. The data obtained from the measurements were calculated using equation 2 below.

$$\mathrm{TA}(\%) = \frac{V \times N \times Meq \times 100}{\mathrm{Y}} \qquad (2)$$

where; TA = titratable acidity (as % citric acid), V = volume of NaOH used, N = normality of NaOH, Meq = weight of a milliequivalent of citric acid (0.064 g), and Y = volume of tomato extract used (10 mL).

For the determination of total soluble solids, one drop of the clear juice was measured with a digital refractometer Atago PAL-1 (3810), 0.0-53.0 Brix (Tokyo, Japan) and expressed as °Brix (AOAC, 1990).

2.4. Statistical Analysis

This study was conducted according to the random plots trial design. Statistical analysis was performed using the JMP package version 5.0. Results were presented as means±standard errors (n=3) for the treatments. Differences between means were analyzed by one-way analysis of variance (ANOVA) followed by the LSD test, and the degree of difference was indicated by letters at the 5 % level. Heat map of Pearson's correlation coefficient matrix and principal component analysis of the evaluated attributes were produced by OriginPro 2019b (32Bit).

3. Results

3.1. Yield and Yield Components in Tomato

The effects of increasing concentrations of sodium chloride in the nutrient solution applied to the solid medium on the yield and its components in tomato are given in Figure 1a-c.

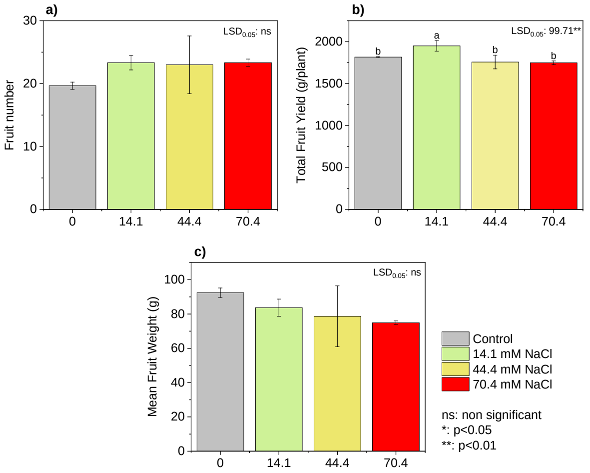

Figure 1. Effect of NaCl concentrations on the yield and its components in tomato. a= Fruit number, b= Total fruit yield, c= Mean fruit weight.

The effect of increasing the NaCl concentration in the nutrient solution on total fruit yield was significant at the $P<0.01$ level, while the effect on average fruit weight and number of fruits was insignificant. Compared to the control, the 14.1 mM NaCl treatment increased total fruit yield by 7.34%, but the 44.4 mM and 70.4 mM NaCl treatments reduced yield by 3.25% and 3.74%, respectively. However, these decreases were not statistically significant compared to the control.

3.2. Biophysical Quality Characteristics

The effects of increasing concentrations of NaCl in the nutrient solution applied to the solid medium on the biophysical quality characteristics of tomato fruits are given in Table 1.

Table 1. Effect of NaCl Concentrations on the Biophysical Quality Characteristics of Tomato Fruits

NaCl (mM)	Fruit size (mm)	Fruit diameter (mm)	Fruit shape index	Fruit firmness (kgf cm^{-2})
0 (Control)	52.5 ± 1.25ab	60.4 ± 0.59a	0.86 ± 0,03	2.46±0.10b
14.1	52.8 ± 1.26a	59.0 ± 1.10ab	0.89 ± 0,01	2.64±0.10b
44.4	48.3 ± 1.02bc	53.2 ± 1.00c	0.90 ± 0,02	3.75±0.08a
70.4	46.9 ± 0.51c	56.0 ± 0.83bc	0.83 ± 0,01	3.41±0.07a
$LSD_{0.05}$	4.21	3.60		0.34
Significance	*	**	ns	**

Each value represents mean ± SE (n = 3); There is no significant difference at 0.05 between means shown with the same letters; ns: Non-significant; *significant at 5%; **significant at 1% level.

The effects of increased NaCl concentration in the nutrient solution on fruit diameter and fruit firmness were significant at the $P<0.01$ level and on fruit size at the $P<0.05$ level, while the effect on fruit shape index was insignificant (Table 1). The addition of 14.1 mM and 44.4 mM NaCl to the nutrient solution had no effect on fruit size compared to the control; however, the addition of 70.4 mM NaCl decreased fruit size. Fruit diameter decreased and fruit firmness increased with increasing salt concentration compared to the control (Table 1).

3.3. Organoleptic Quality

3.3.1. Commercial quality characteristics

The effects of increasing concentrations of NaCl in the nutrient solution applied to the solid medium on the commercial quality characteristics of tomato fruits are given in Table 2.

Table 2. Effect of NaCl Concentrations on the Commercial Quality Characteristics of Tomato Fruits

NaCl (mM)	a*	b*	L*	h°	C*	Tomato Color Index
0 (Control)	18.86 ± 0.55 b	26.76 ± 0.67 a	45.49 ± 0.45 ab	54.80 ± 1.39 a	32.77 ± 0.36	25.36 ± 1.12 b
14.1	20.20 ± 0.04 a	25.16 ± 0.01 b	43.47 ± 0.21 c	51.25 ± 0.06 b	32.26 ± 0.03	28.80 ± 0.11 a
44.4	20.76 ± 0.31 a	24.52 ± 0.35 b	46.44 ± 0.23 a	49.74 ± 0.81 b	32.14 ± 0.09	28.40 ± 0.04 a
70.4	20.96 ± 0.08 a	24.63 ± 0.04 b	44.92 ± 0.21 b	49.60 ± 0.10 b	32.34 ± 0.07	28.86 ± 0.08 a
$LSD_{0.05}$	1.27	1.51	1.15	3.22		2.24
Significance	*	*	**	*	ns	*

Each value represents mean ± SE (n = 3); There is no significant difference at 0.05 between means shown with the same letters; ns: Non-significant; *significant at 5 %; **significant at 1 % level.

The effect of increased NaCl concentration in the nutrient solution on the L* value of the fruit skin colour was significant at the $P<0.01$ level, while the effects on the a* value, b* value, h° value, and color index value were significant at the $P<0.05$ level. However, the effect of increasing the salt concentration in the nutrient solution on the fruit skin colour value was statistically insignificant (Table 2).

In the skin of tomato fruit, the a* value increased and the b* value decreased at NaCl treatments. However, the effects of the different salt concentrations on the a* and b* values of the fruit skin were similar. The L* value of tomato fruit skin decreased when 14.1 mM NaCl was added to the nutrient solution compared to the control.

On the other hand, the values obtained from 44.4 mM and 70.4 mM NaCl treatments were similar to those obtained from the control. The hue angle value of the skin of tomato fruits showed a decrease in the salt treatment compared to the control. However, this decrease was similar for the NaCl concentrations used. In other words, the hue angle values of tomato fruit skins grown with different concentrations of salt application were close to each other. The color index of tomato fruit skin increased with salt treatment compared to the control. This increase was similar at different salt levels (Table 2).

3.3.2. Physico-chemical quality characteristics

The effects of increasing concentrations of NaCl in the nutrient solution applied to the solid medium on the physico-chemical quality characteristics of tomato fruits are given in Figure 2a-e.

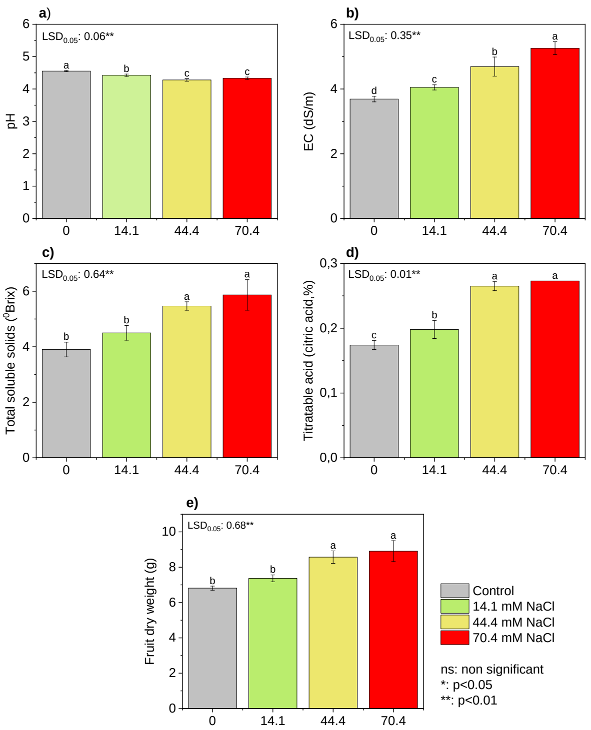

Figure 2. Effect of NaCl concentrations on the physico-chemical quality characteristics of tomato fruits. a= pH of tomato juice, b= EC of tomato juice, c= Total soluble solids, d= Titratable acid, e= Fruit dry matter.

The effects of increasing the NaCl concentrations in the nutrient solution on the pH and EC values, the titratable acidity in the fruit juice, and fruit dry matter were significant at the P<0.01 level, while the effect on the total soluble solids (°Brix) in the fruit was significant at the P<0.05 level. As the salt concentration in the nutrient solution increased, the pH of the tomato fruit juice decreased, while the EC value, the total soluble solids and the percentage of titratable acidity of the juice increased compared to the control (Figure 2a-d). At 44.4 mM and 70.4 mM NaCl concentration in the nutrient solution, the pH values of tomato fruit juice were low and similar to the control (Figure 2a). On the other hand, the total soluble solids in the tomato fruits were high and close to each other at medium (44.4 mM) and high (70.4 mM) NaCl concentrations compared to the control (Figure 2c). The dry matter (%) in the fruits increased with increasing NaCl concentration in the nutrient solution. However, these increases were found to be significant at 44.4 mM and 70.4 mM NaCl concentrations compared to the control. Application of 14.1 mM NaCl in the nutrient solution had no significant effect on fruit dry matter compared to the control (Figure 2e).

3.4. Heat Map Pearson Correlation and Principal Component Analysis

The results of the correlation relationships between the yield components and fruit quality characteristics examined in the study are shown in Figure 3. The correlation results revealed that there were significant relationships between the analyzed parameters at the P<0.01 and P<0.05 levels. While b*, h°, TA and FDM showed the most significant correlations, no significant correlation was found for FSI with any of the characteristics analyzed in the study. In addition, the highest positive correlation (P<0.01; 0.98) was found between h° and b*, while the highest negative correlation (P<0.01; -0.98) was found between h° and a*. Moreover, the correlation relationship between b* and FS was the least significant positive relationship (0.59) at P<0.05, while the correlation relationships between FDM and TFP and between TSS and MFW were the least significant negative relationships (-0.58).

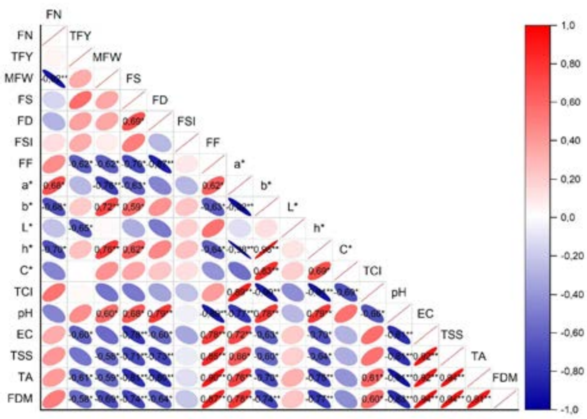

Figure 3. Heatmap of Pearson's correlation coefficient matrix between various yield and fruit quality attributes of tomato under NaCl applications. The values in the figure are Pearson's correlation coefficient. * and ** denote correlation coefficients that are significant at P<0.05 and P<0.01 level, respectively. NF= fruit number, TFY= total fruit yield, MFW= mean fruit weight, FS= fruit size, FD= fruit diameter, FSI= fruit shape index, FF= fruit firmness, a*= red/green value, b*=blue/yellow value, L*= lightness, h°= hue angle, C*= chroma, TCI= total color index, pH= potential of hydrogen ions, EC= electrical conductivity, TSS= total soluble soilds, TA= titratable acid, FDM= fruit dry matter.

The principal component analysis of the studied attributes is given in Figure 4. The contributions of different components of PCA are presented on the x-axis

(PC1) and y-axis (PC2). PC1 (58.9%) and PC2 (16.9%) exhibited the highest contributions in terms of percentage variance and represented 75.8% of the total variance in the dataset (Figure 4).

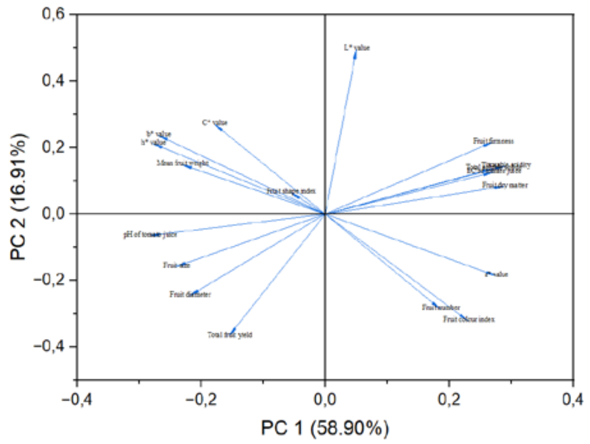

Figure 4. Grouping of the variables in principal components.

Figure 4 shows that the variables fruit firmness, total soluble solids, titratable acidity, EC value in the fruit juice and dry matter content in the fruit are related to each other in the same direction and the relationship between them is strong. The variables fruit hardness, total soluble solids, titratable acidity, EC in the fruit juice and dry matter content in the fruit have an inverse relationship with the variables pH value, fruit length, fruit diameter and yield. There is a positive correlation between the pH value of the fruit juice, the size of the fruit, the diameter of the fruit and the yield variables. The relationship between L* and the yield variables is inverse. The color index of the tomato, a* and the fruit number variables are positive and strongly correlated. Chroma, fruit shape index, average fruit weight, h° and b* are positively correlated. These variables are only weakly correlated with the FSI and the other variables are strongly correlated with each other. Conversely, chroma, fruit shape index, average fruit weight, h* and b* showed a negative correlation with the color index of the tomato, a* and the number of fruits.

4. Discussion

In the present study, the increasing salt concentration in the nutrient solution partially decreased the mean fruit weights, but this decrease was not statistically significant (Figure 1c). The differences in fruit number and weight may also be attributed to how plants allocate their resources under varying salinity conditions. In the absence of additional stress from NaCl, the plants may have prioritized fruit weight over quantity, resulting in fewer but larger fruits. Sánchez-González et al. (2016) reported that high salt levels caused a sharp decrease in the fresh weight of tomatoes. The decrease in fruit weight under saline conditions has been attributed to less water uptake by the root and thus reduced water transport to the fruit (Sakamoto et al., 1999). Likewise, Zhang et al. (2016) reported that salt stress reduced water uptake in the plant root through an osmotic effect and subsequently induced water stress.

Our results, in which we found the effect of increasing salt concentration in the nutrient solution on fruit number to be insignificant (Figure 1a), support the results found by Li et al. (2001) and Ehret et al. (2013). On the other hand, Zhang et al. (2017) observed that the total number of fruits per plant decreased under salinity in tomato plants grown in hydroponic culture.

While total fruit yield increased significantly by 7.34% with the addition of 14.1 mM NaCl to the nutrient solution compared to the control, it decreased by 3.25% and 3.77% with 44.4 mM and 70.4 mM NaCl treatments, respectively. However, these decreases were not statistically significant compared to the control (Figure 1b). Botella et al. (2021) reported that marketable fruit yield in tomato plants under control conditions was 91.8%, while it decreased to 80.5% in those grown under salt stress (60 mM NaCl). Similarly, Moya et al. (2017) reported a decrease in total and marketable fruit yield in tomatoes grown under salinity treatments (EC: 4.5 $dS{\cdot}m^{-1}$). Salt stress reduces marketable yield by reducing fruit size (Zhang et al., 2022).

Adding NaCl at 14.1 mM and 44.4 mM concentrations to the nutrient solution did not affect fruit size compared to the control; however, NaCl application at a concentration of 70.4 mM significantly reduced fruit size (Table 1). Many researchers have observed that fruit size decreased significantly with increasing salt application doses (Fernández-García et al., 2004; Ehret et al., 2013). Exposure to high salinity lowers the water potential of the plant, reducing water flow to the fruit and ultimately minimizing the rate of fruit expansion (Johnson et al., 1992).

In the present study, the effect of different salt levels in the nutrient solution on fruit shape index was found to be insignificant (Table 1). ''Fruit shape index'' is defined as the ratio of the maximum length of a fruit to its maximum width. Specifically, the rate, duration, and plane of cell division and isotropic and anisotropic cell growth contribute significantly to the eventual morphology of plant organs (Wu et al., 2018). In horticulture, fruit shape is an important feature that not only satisfies people's curiosity but also distinguishes varieties within a given plant species (Wang et al., 2019).

As the salt concentration in the nutrient solution increased, the fruit firmness of the tomato increased compared to the control (Table 1). Reports on the effects of salinity on tomato fruit hardiness have been controversial. Botella et al. (2000), and Schwarz et al. (2001) reported that tomato fruit firmness increased with an increasing salt level in the root zone. Increased fruit firmness depends on the intensity of salt stress and the tomato variety (Ruiz et al., 2015). On the other hand, Krauss et al. (2006) reported that salinity reduces fruit firmness. It was reported that fruit firmness decreased at high salt levels above 10 $dS{\cdot}m^{-1}$ in the root zone of tomatoes (Cuartero and Fernández Muñoz, 1999). The texture of fresh tomatoes is determined by the firmness of the flesh and the thickness of the skin (Kader et al., 1978). Softening during storage, distribution, and ripening of tomatoes can be a big issue since it increases their vulnerability to harm (Batu, 2004). Fruit cracking is affected by variety, size, firmness, shape, fruit development, fruit cuticle and sugar content, irrigation water quality, and environmental conditions (Abdollah, 2015).

In the current study, the salt treatment mainly showed positive effects on tomato fruit's commercial quality parameters (Table 2). The a* value is a good parameter for the development of the red colour and the degree of maturity of the tomato, while the b* value indicates a yellow discolouration (Artés et al., 1999). Fruit color affects consumer acceptance and perception of taste and aroma (Hoppu et al., 2018; Shen et al., 2018). Chlorophylls and carotenoids accumulated in the epidermis, lower epidermal layer, and pericarp are responsible for the fruit color of tomatoes (Lado et al., 2016; Llorente et al., 2017; Dono et al., 2020).

In the present study, as the salt concentration increased in the nutrient solution, the pH value of tomato fruit juice decreased while the EC value increased compared to the control (Figure 2a-b). Botella et al. (2021) reported that the pH value decreased in tomato fruit juice as salinity increased. On the other hand, it has been reported that the pH and EC values of tomato juice did not change significantly under salt stress compared to the control (Azarmi et al., 2010; Moya et al., 2017).

As the salt concentration increased in the nutrient solution, the total soluble solids content of tomato fruit juice increased compared to the control (Figure 2c). Similar findings were obtained by Ruiz et al. (2015), Huang et al. (2016) and El-Mogy et al. (2018). The increase in soluble solids content of tomato fruit exposed to sodium chloride was also attributed to a reduction in water transport to the fruit. However, it has been reported that the taste of tomato improves with salinity (Nakahara et al., 2019). Regarding human nutrition, salt effects on tomato fruit should not necessarily be seen as unfavorable (Martínez et al., 2020). Total soluble solids (°Brix) are a good indicator of total soluble sugars, and the increase in Brix itself is a consequence of the salt-induced improvement in fruit quality (Sánchez-González et al., 2015; Van Meulebroek et al., 2016). It is well established that manipulating central organic acids is a promising approach to improving fruit yield in tomatoes (Martínez et al., 2020). Citric and malic acid accumulation plays a crucial role in the ripening stage of fruit and can provide sugars to the fruit through neo-glucogenesis (Quinet et al., 2019).

In the present study, titratable acidity increased with an increasing salt concentration in the nutrient solution (Figure 2d). Our results for this parameter were in agreement with the results found by Agius et al. (2022) and Zhang et al. (2022). The positive effect of salinity on tomato quality is due to the high concentration of titratable acid and sugar in the juice (Krauss et al., 2006).

In our study, dry matter in fruits increased significantly at medium (44.4 mM) and high (70.4 mM) NaCl administrations (Figure 2e). According to Sánchez-González et al. (2015), the percentage of dry matter increased in tomato fruits grown at high salinity (0.7 $S \cdot m^{-1}$) compared to tomatoes grown at low salinity (0.5 $S \cdot m^{-1}$). In addition, the low dry matter content of the fruit in the control group supports the positive effects of the NaCl treatment on the dry weight of the fruit. Salt treatments can reduce water uptake by creating osmotic stress in the plant, which contributes to an increase in the dry matter content of the fruit. Consequently, controlled salt stress treatments can improve fruit quality by increasing the dry matter content of the fruit. Salt application in soilless agriculture, when applied correctly, can be an effective method for enhancing stress tolerance in plants and achieving higher quality produce. However, the potential risks of this method should also be considered, and the system should be regularly monitored.

5. Conclusion

This study investigated the effects of varying NaCl concentrations in nutrient solutions on the yield and quality of tomato fruits. The application of 14.1 mM NaCl significantly increased total fruit yield. Additionally, moderate NaCl concentrations generally enhanced several quality traits of the fruits. In contrast, higher salt levels led to reductions in fruit size and diameter. These results indicate that the careful management of salt levels in nutrient solutions can effectively improve specific market-desired qualities in tomatoes while maintaining overall yield.

Author Contributions

The percentages of the authors' contributions are presented below. All authors reviewed and approved the final version of the manuscript.

	G.A.	A.K.	S.D.	S.R.	Z.C.
C	50	50	-	-	-
D	60	40	-	-	-
S	80	20	-	-	-
DCP	60	-	10	10	20
DAI	50	25	25	-	-
L	60	40	-	-	-
W	100	-	-		
CR	50	40	10	-	-
SR	100	-	-	-	-
PM	100	-	-	-	-

C= concept, D= design, S= supervision, DCP= data collection and/or processing, DAI= data analysis and/or interpretation, L= literature search, W= writing, CR= critical review, SR= submission and revision, PM= project management.

Conflict of Interest

The authors declared that there is no conflict of interest.

Ethical Consideration

Ethics committee approval was not required for this study because there was no study on animals or humans.

Acknowledgments

The corresponding author, G.A., thanks colleagues for their support and help through the period of this research. This work was financially supported by the Ondokuz Mayis University Research Fund (Project number: PYO.ZRT.1908.22.015).

References

Abdollah KK. 2015. Physiological and genetic factors influencing fruit cracking. Acta Physiol Plant, 37(1): 1718.

Agius C, Von Tucher S, Rozhon W. 2022. The effect of salinity on fruit quality and yield of cherry tomatoes. Horticulturae, 8(1): 59.

Alam AU, Rathi P, Beshai H, Sarabha GK, Deen MJ. 2021. Fruit quality monitoring with smart packaging. Sensors (Basel), 21(4): 1509.

Alpaslan M, Güneş A, Inal A. 1998. Deneme Tekniği [Trial Technique]. Ankara Üniversitesi Yayın No: 1501, Ziraat Fakültesi Ders Kitabı, Ankara, Türkiye, pp: 455.

Alsuhaibani AMA. 2018. Chemical composition and ameliorative effect of tomato on isoproterenol-induced myocardial infarction in rats. Asian J Clin Nutr, 10(1): 1-7.

Amit SK, Uddin MM, Rahman R, Rezwanul Islam SM, Khan MS. 2017. A review on mechanisms and commercial aspects of food preservation and processing. Agric Food Secur, 6: 51.

AOAC. 1990. Association of Official Analytical Chemists, Official Methods of Analysis, 13th edition. AOAC, Washington DC, USA, pp: 120.

Arah IK, Amaglo H, Kodzo E, Kumah EK, Hayford O. 2015. Preharvest and postharvest factors affecting the quality and shelf life of harvested tomatoes: A mini review. Int J Agron, 2015: 478041.

Arif Y, Singh P, Siddiqui H, Bajguz A, Hayat S. 2020. Salinity induced physiological and biochemical changes in plants: An omic approach towards salt stress tolerance. Plant Physiol Biochem, 156: 64-77.

Artés F, Conesa MA, Hernández S, Gil MI. 1999. Keeping quality of fresh-cut tomato. Postharvest Biol Technol, 17: 153-162.

Asensio E, Sanvicente I, Mallor C, Menal-Puey S. 2019. Spanish traditional tomato. Effects of genotype, location and agronomic conditions on the nutritional quality and evaluation of consumer preferences. Food Chem, 270: 452-458.

Ávalos-Sánchez E, López-Martínez A, Molina-Aiz FD, Reca J, Marín-Membrive P, Valera-Martínez DL. 2022. Effect of different substrates, and irrigation with water with different saline concentrations, on the development of tomato fungal diseases in an almería-type greenhouse. Agronomy, 12: 1050.

Azarmi R, Taleshmikail RD, Gikloo A. 2010. Effects of salinity on morphological and physiological changes and yield of tomato in hydroponics system. J Food Agric Environ, 8(2): 573-576.

Batu A. 2004. Determination of acceptable firmness and colour values of tomatoes. J Food Eng, 61(3): 471-475.

Bertin N, Génard M. 2018. Tomato quality as influenced by preharvest factors. Sci Hortic, 233: 264-276.

Botella MA, Del Amor F, Amoros A, Serrano M, Martinez V, Cerda A. 2000. Polyamine, etylene and other physico-chemical parameters in tomato (*Lycorpersicon esculentum*) fruits as affected by salinity. Physiol Plant, 109(4): 428-434.

Botella MÁ, Hernández V, Mestre T, Hellín P, García-Legaz MF, Rivero RM, Martínez V, Fenoll J, Flores P. 2021. Bioactive compounds of tomato fruit in response to salinity, heat and their combination. Agriculture, 11(6): 534.

Coyago-Cruz E, Corell M, Moriana A, Hernanz D, Benítez-González AM, Stinco CM, Meléndez-Martínez AJ. 2018. Antioxidants (carotenoids and phenolics) profile of cherry tomatoes as influenced by deficit irrigation, ripening and cluster. Food Chem, 240: 870-884.

Cuartero J, Fernández Muñoz J. 1999. Tomato and salinity. Sci Hortic, 78(1-4): 83-125.

Cui J, Shao G, Lu J, Keabetswe L, Hoogenboom G. 2019. Yield, quality and drought sensitivity of tomato to water deficit during different growth stages. Sci Agric, 77(2): e20180390.

Distefano M, Mauro RP, Page D, Giuffrida F, Bertin N, Leonardi C. 2022. Aroma volatiles in tomato fruits: The role of genetic, preharvest and postharvest factors. Agronomy, 12(2): 376.

Dono G, Rambla JL, Frusciante S, Granell A, Diretto G, Mazzucato A. 2020. Color mutations alter the biochemical composition in the San Marzano tomato fruit. Metabolites, 10(3): 110.

Ehret DL, Usher K, Helmer T, Block G, Steinke D, Frey B, Kuang T, Diarra M. 2013. Tomato fruit antioxidants in relation to salinity and greenhouse climate. J Agric Food Chem, 61(5): 1138-1145.

El-Mogy MM, Garchery C, Stevens R. 2018. Irrigation with salt water affects growth, yield, fruit quality, storability and marker-gene expression in cherry tomato. Acta Agric Scand, B-Soil Plant Sci, 68(8): 727-737.

Fernández-García N, Martínez V, Carvajal M. 2004. Effect of salinity on growth, mineral composition, and water relations of grafted tomato plants. J Plant Nutr Soil Sci, 167(5): 616-622.

Fussy A, Papenbrock J. 2022. An overview of soil and soilless cultivation techniques—chances, challenges and the neglected question of sustainability. Plants, 11(9): 1153.

Gonçalves DC, Morgado CMA, De Oliveira Aguiar FC, Silva EP, De Carvalho Correa G, Dos Reis Nascimento A, Carlos R, Junior C. 2020. Postharvest behavior and lycopene content of tomatoes at different harvest times. Acta Sci Technol, 42: e48403.

Gül A. 2012. Topraksız tarım [Soilless Culture]. Hasad Yayıncılık Ltd. Şti., İstanbul, Türkiye, ss: 140.

Hobson GE, Adams P, Dixon TJ. 1983. Assessing the colour of tomato fruit during ripening. J Sci Food Agric, 34: 286-292.

Hoppu U, Puputti S, Aisala H, Laaksonen O, Sandell M. 2018. Individual differences in the perception of color solutions. Foods, 7(9): 154.

Huang C, Peng F, You Q, Xue X, Wang T, Liao J. 2016. Growth, yield and fruit quality of cherry tomato irrigated with saline water at different developmental stages. Acta Agric Scand, B-Soil Plant Sci, 66: 317-324.

Iglesias MJ, García-Lopez J, Collados-Luján JF, López-Ortiz F, Díaz M, Toresano F, Camacho F. 2015. Differential response to environmental and nutritional factors of high-quality tomato varieties. Food Chem, 176: 278-287.

Izzo L, Castaldo L, Lombardi S, Gaspari A, Grosso M, Ritieni A. 2022. Bioaccessibility and antioxidant capacity of bioactive compounds from various typologies of canned tomatoes. Front Nutr, 9: 849163.

Johnson RW, Dixon MA, Lee DR. 1992. Water relations of the tomato during fruit growth. Plant, Cell Environ, 15(8): 947-953.

Kader AA, Morris LL, Chen P. 1978. Evaluation of two objective methods and a subjective rating scale for measuring tomato fruit firmness. J Am Soc Hortic Sci, 103(1): 70-73.

Korkmaz A, Karagöl A, Akınoğlu G, Korkmaz H. 2018. The effects of silicon on nutrient levels and yields of tomatoes under saline stress in artificial medium culture. J Plant Nutr, 41(1): 123-135.

Krauss S, Schnitzler WH, Grassmann J, Woitke M. 2006. The influence of different electrical conductivity values in a simplified recirculating soilless system on inner and outer fruit quality characteristics of tomato. J Agric Food Chem, 54: 441-448.

Ladewig P, Trejo-Téllez LI, Servín-Juárez R, Contreras-Oliva A, Gomez-Merino FC. 2021. Growth, yield and fruit quality of Mexican tomato landraces in response to salt stress. Not Bot Horti Agrobo Cluj, 49(1): 12005.

Lado J, Zacarías L, Rodrigo MJ. 2016. Regulation of carotenoid biosynthesis during fruit development. Subcell Biochem, 79: 161-198.

Lancaster JE, Lister C, Reay PF, Triggs CM. 1997. Influence of pigment composition on skin color in a wide range of fruits and vegetables. J Am Soc Hortic Sci, 122: 594-598.

Lara I, Heredia A, Domínguez E. 2019. Shelf life potential and the fruit cuticle: The unexpected player. Front Plant Sci, 10: 770.

Li YL, Stanghellini C, Challa H. 2001. Effect of electrical conductivity and transpiration on production of greenhouse tomato (*Lycopersicon esculentum* L.). Sci Hortic, 88(1): 11-29.

Lima GPP, Gómez HAG, Seabra Junior S, Maraschin M, Tecchio MA, Borges CV. 2022. Functional and nutraceutical compounds of tomatoes as affected by agronomic practices, postharvest management, and processing methods: A mini review. Front Nutr, 9: 868492.

Llorente B, Martinez-Garcia JF, Stange C, Rodriguez-Concepcion M. 2017. Illuminating colors: regulation of carotenoid biosynthesis and accumulation by light, Curr Opin Plant Biol, 37: 49-55.

Lu T, Yu H, Wang T, Zhang T, Shi C, Jiang W. 2022. Influence of the electrical conductivity of the nutrient solution in different phenological stages on the growth and yield of cherry tomato. Horticulturae, 8: 378.

Lucke T, Walker C, Beecham S. 2019. Experimental designs of field-based constructed floating wetland studies: A review. Sci Total Environ, 660: 199-208.

Ma Y, Dias MC, Freitas H. 2020. Drought and salinity stress responses and microbe-induced tolerance in plants. Front Plant Sci, 11: 591911.

Mareri L, Parrotta L, Cai G. 2022. Environmental stress and plants. Int J Mol Sci, 23(10): 5416.

Martínez JP, Fuentes R, Farías K, Lizana C, Alfaro JF, Fuentes L, Calabrese N, Bigot S, Quinet M, Lutts S. 2020. Effects of salt stress on fruit antioxidant capacity of wild (*Solanum chilense*) and domesticated (*Solanum lycopersicum* var. cerasiforme) tomatoes. Agronomy, 10(10): 1481.

Mascarello G, Pinto A, Parise N, Crovato S, Ravarotto L. 2015. The perception of food quality. Profiling Italian consumers. Appetite, 89: 175-182.

Mcguire RG. 1992. Reporting of objective color measurements. HortScience, 27(12): 1254.

Moya C, Oyanedel E, Verdugo G, Flores MF, Urrestarazu, M, Álvaro JE. 2017. Increased electrical conductivity in nutrient solution management enhances dietary and organoleptic qualities in soilless culture tomato. HortScience, 52(6): 868-872.

Nakahara H, Uemura Y, Nakashima Y, Mineda E, Nahashima N, Matsuzoe N. 2019. Evaluating the taste of tomato cultivated under salt-stress conditions by component change, sensory evaluation, and taste sensor. Environ Control Biol, 57(4): 99-106.

Nangare DD, Singh Y, Kumar PS, Minhas PS. 2016. Growth, fruit yield and quality of tomato (*Lycopersicon esculentum* Mill.) as affected by deficit irrigation regulated on phenological basis. Agric Water Manag, 171: 73-79.

Petrescu DC, Vermeir I, Petrescu-Mag RM. 2019. Consumer understanding of food quality, healthiness, and environmental impact: A cross-national perspective. Int J Environ Res Public Health, 17(1): 169.

Quinet M, Angosto T, Yuste-Lisbona FJ, Blanchard-Gros R, Bigot S, Martínez JP, Lutts S. 2019. Tomato fruit development and metabolism. Front Plant Sci, 10: 1554.

Rana N, Ghabru A, Vaidya D. 2019. Defensive function of fruits and vegetables. J Pharmacogn Phytochem, 8(3): 1872-1877.

Rodríguez F, Pedreschi R, Fuentealba C, de Kartzow A, Olaeta JA, Alvaro JE. 2019. The increase in electrical conductivity of nutrient solution enhances compositional and sensory properties of tomato fruit cv. Patrón. Sci Hortic, 244: 388-398.

Ruiz MS, Yasuor H, Ben-Gal A, Yermiyahu U, Saranga Y, Elbaum R. 2015. Salinity induced fruit hypodermis thickening alters the texture of tomato (*Solanum lycopersicum* Mill) fruits. Sci Hortic, 192: 244-249.

Sajdakowska M, Gębski J, Gutkowska K, Żakowska-Biemans S. 2018. Importance of health aspects in Polish consumer choices of dairy products. Nutrients, 10: 1007.

Sakamoto Y, Watanabe S, Nakashima T, Okano K. 1999. Effects of salinity at two ripening stages on the fruit quality of single-truss tomato grown in hydroponics. J Hortic Sci Biotechnol, 74(6): 690-693.

Sánchez-González M, Sánchez-Guerrero MC, Medrano E, Porras ME, Baeza EJ, Lorenzo P. 2015. Influence of pre-harvest factors on quality of a winter cycle high commercial value tomato cultivar. Sci Hortic, 189(3): 104-111.

Sánchez-González MJ, Schouten RE, Tijskens LMM, Cruz Sanchez-Guerrero M, Medrano E, Del Rio-Celestino M, Lorenzo P. 2016. Salinity and ripening on/off the plant effects on lycopene synthesis and chlorophyll breakdown in hybrid Raf tomato. Sci Hortic, 211: 203-212.

Schwarz D, Kläring HP, Ingram KT, Hung YC. 2001. Model-based control of nutrient solution concentration influences tomato growth and fruit quality. J Am Soc Hortic Sci, 126: 778-784.

Shen M, Shi L, Gao Z. 2018. Beyond the food label itself: How does color affect attention to information on food labels and preference for food attributes? Food Qual Prefer, 64(6): 47-55.

Shrivastava P, Kumar R. 2015. Soil salinity: A serious environmental issue and plant growth promoting bacteria as one of the tools for its alleviation. Saudi J Biol Sci, 22(2): 123-131.

Sonneveld C, Straver N. 1994. Nutrient solutions for vegetables and flowers grown in water or substrates, Serie, Voedingsoplossingen Glasstuinbouw, No:8, PBG Naaldwijk-PBG Aalsmeer, Noord Holland, Nederland, 10th ed., pp: 1-45.

Sonneveld C, Van Der Burg AMM. 1991. Sodium chloride salinity in fruit vegetable crops in soilless culture. Neth J Agric Sci, 39: 115-122.

Talens P, Mora L, Bramley PM, Fraser PD. 2016. Antioxidant compounds and their bioaccessibility in tomato fruit and puree obtained from a Detiolated-1 (DET-1) down-regulated genetically modified genotype. Food Chem, 213: 735-741.

Thole V, Vain P, Yang R-Y, Almeida Barros Da Silva J, Enfissi

EMA, Nogueira M, Price EJ, Alseekh S, Fernie AR, Fraser PD, Hanson P, Martin C. 2020. Analysis of tomato post-harvest properties: Fruit color, shelf life, and fungal susceptibility. Curr Protoc Plant Biol, 5(2): e20108.

Tomas M, Beekwilder J, Hall RD, Sagdic O, Boyacıoğlu D, Capanoğlu E. 2017. Industrial processing versus home processing of tomato sauce: Effects on phenolics, flavonoids and in vitro bioaccessibility of antioxidants. Food Chem, 220: 51-58.

Toscano S, Trivellini A, Cocetta G, Bulgari R, Francini A, Romano D, Ferrante A. 2019. Effect of preharvest abiotic stresses on the accumulation of bioactive compounds in horticultural produce. Front Plant Sci, 10: 1212.

Tüzel Y, Gül A, Tüzel IH, Öztekin GB. 2019. Different soilless culture systems and their management. J Agric Food Environ Sci, 73(3): 7-12.

Tzortzakis N, Nicola S, Savvas D, Voogt W. 2020. Editorial: Soilless cultivation through an intensive crop production scheme. Management strategies, challenges and future directions. Front Plant Sci, 11: 363.

Tzortzakis N, Pitsikoulaki G, Stamatakis A, Chrysargyris A. 2022. Ammonium to total nitrogen ratio interactive effects with salinity application on *Solanum lycopersicum* growth, physiology, and fruit storage in a closed hydroponic system Agronomy, 12(2): 386.

Urrestarazu M, Morales I, La Malfa T, Checa R, Wamser AF, Alvaro JE. 2015. Effects of fertigation duration on the pollution, water consumption, and productivity of soilless vegetable cultures. HortScience, 50(6): 819-825.

Van Meulebroek L, Hanssens J, Steppe K, Vanhaecke L. 2016. Metabolic fingerprinting to assess the impact of salinity on carotenoid content in developing tomato fruits. Int J Mol Sci, 17(6): 821.

Wang YP, Clevenger JP, Illa-Berenguer E, Meulia T, Van Der Knaap E, Sun L. 2019. A comparison of sun, ovate, fs8.1 and auxin application on tomato fruit shape and gene expression. Plant Cell Physiol, 60(5): 1067-1081.

Wu S, Zhang B, Keyhaninejad N, Rodríguez GR, Kim HJ, Chakrabarti M, Illa-Berenguer E, Taitano NK, Gonzalo MJ, Díaz A, Pan Y, Leisner CP, Halterman D, Buell CR, Weng Y, Jansky SH, Van Eck H, Willemsen J, Monforte AJ, Meulia T, Van Der Knaap E. 2018. A common genetic mechanism underlies morphological diversity in fruits and other plant organs. Nat Commun, 9(1): 4734.

Wu X, Yu L, Pehrsson PR. 2022. Are processed tomato products as nutritious as fresh tomatoes? Scoping review on the effects of industrial processing on nutrients and bioactive compounds in tomatoes. Adv Nutr, 13(1): 138-151.

Zhang P, Jiang S, Dai Y, Zhang Z, Senge M. 2022. Combined treatment of salinity stress and fruit thinning effect on tomato. Front Nutr, 9: 857977.

Zhang P, Senge M, Dai Y. 2016. Effects on salinity stress on growth, yield, fruit quality and water use efficiency of tomato under soilless cultivation. Rev Agric Sci, 4: 46-55.

Zhang P, Senge M, Dai Y. 2017. Effects of salinity stress at different growth stages on tomato growth, yield, and water-use efficiency. Commun Soil Sci Plant Anal, 48(6): 624-634.

Black Sea Journal of Agriculture

doi: 10.47115/bsagriculture.1563898

Open Access Journal
e-ISSN: 2618 – 6578

Research Article
Volume 8 - Issue 2 : 134-142 / March 2025

MODELLING CHANGES IN MILK COMPONENTS OF DAMASCUS GOATS DURING LACTATION

Nazire MİKAİL[1]*, Ayhan YILMAZ[2], Muhammet Ali KARA[1], Figen CERİTOĞLU[1], Ercan GÜNEŞ[3]

[1]Siirt University, Faculty of Agriculture, Department of Animal Husbandry, Siirt, Türkiye
[2]Bitlis Eren University, Faculty of Health Sciences, Department of Nutrition and Dietetics, Bitlis, Türkiye
[3]Provincial Directorate of Agriculture and Forestry, Animal Health Breeding and Fisheries Branch Directorate, Siirt, Türkiye

Abstract: In this study, the possibilities of determining the changes of lactation milk components in Damascus goats by mathematical models were investigated. The animal material of the study consisted of 47 Damascus goats raised in Gökçebağ village of Siirt province. Milk components were analyzed in milk samples acquired at 2-week intervals after parturition. Milk components were analyzed using the Lactoscan Milk Analyzer. Wood and Ali-Schaeffer models, which are assumed to be the most appropriate for the definition of lactation curves, were applied to the milk component data obtained to describe the change in milk components, the best fitting model was determined, mathematical and biological relationships were solved in protein and fat content, and the relationship between the parameters was examined. Samples taken from dairy goats in the local enterprise were expressed with mathematical models and the change in milk content during lactation was tried to be learned. The results are intended to form the basis for the improvement of goat milk content and breeding projects in Siirt.

Keywords: Milk component, Protein, Fat, Wood model, Ali Schaeffer model

***Corresponding author:** Siirt University, Faculty of Agriculture, Department of Animal Husbandry, Siirt, Türkiye
E mail: naziremikail@siirt.edu.tr (N. MİKAİL)
Nazire MİKAİL https://orcid.org/0000-0002-8996-9330
Ayhan YILMAZ https://orcid.org/0000-0002-5990-7550
Muhammet Ali KARA https://orcid.org/0000-0003-3203-8364
Figen CERİTOĞLU https://orcid.org/0000-0003-4016-0394
Ercan GÜNEŞ https://orcid.org/0009-0001-1843-4734

Received: July 02, 2024
Accepted: November 17, 2024
Published: March 15, 2025

Cite as: Mikail N, Yılmaz A, Kara MA, Ceritlioğlu F, Güneş E. 2025. Modelling changes in milk components of Damascus goats during lactation. BSJ Agri, 8(2): 134-142.

1. Introduction

Goat breeding is an important component of small ruminant production worldwide and in Türkiye. Türkiye's geographic structure, soil characteristics, and vegetation provide a favorable environment for goat farming. Additionally, goat breeding plays a significant economic role in rural areas due to its minimal land requirements and adaptability to harsh conditions (Park and Haenlein, 2006; Paksoy, 2007; Kaymakçı and Engindeniz, 2010). According to FAO (2014), goats contribute 2.4% of the world's milk production. In Türkiye, 90.8% of milk production comes from cattle, 8.88% from small ruminants, and the remainder from buffaloes."Of the small ruminants' contribution, 6.28% comes from sheep and 2.60% from goats (Semerci and Çelik, 2016).

Milk composition, particularly fat and protein content, varies significantly in goat milk depending on factors such as breed, season, lactation period, and nutrition. Goat milk contains approximately 4.5% fat and features a higher proportion of short and medium-chain fatty acids compared to cow milk, offering distinct nutritional benefits (Yadav et al., 2016; Tüfekçi, 2023). The taste and composition of goat milk are highly dependent on the breed and feeding practices (Raynal-Ljutovac et al., 2005). Proper maintenance and feeding conditions, particularly in intensive farming systems, can help achieve desired milk quality parameters. Milk content is a critical determinant of milk prices and is linked to quality standards (Raynal-Ljutovac et al., 2008). Variations in milk components, such as fat and protein, are influenced by the lactation stage. For instance, the beginning, middle, and end of lactation may show significant differences in milk composition (Daşkıran et al., 2022). However, studies addressing lactation curves for goats remain limited, despite extensive research on this topic for cattle (e.g., Dağ et al., 2003; Keskin and Tozluca, 2004; Çilek and Keskin, 2008; Zülkadir et al., 2008 Çilek et al., 2009; Keskin et al., 2009a; Keskin et al., 2009b; Gök et al., 2019).

Lactation curves are mathematical representations of milk production patterns throughout the milking period. These curves are essential for evaluating milk yield and determining selection criteria. Knowledge of lactation curves and their parameters in goats are very important for changing the shape of lactation curves and improving these parameters in order to optimize production and benefits (Mousa and Elzarei, 2016). Parity had a large effect on the characteristics of the lactation curve in dairy goats. It was found that peak yield increased with increasing parity up to about the third or fourth parity, while time of peak yield is later for first-parity does than for later parity does (Groenewald and Viljoen, 2003). Models such as Wood, Dhanoa, Wilmink, Cobby and Le Du, Dave, and Inverse Polynomial have been widely used to describe lactation curves (Masselin et al., 1987, Gaddour et al, 2009). Animals with flatter lactation curves are preferred for their consistent yield, efficient maintenance, and reproductive advantages (Wood, 1967; Madsen, 1975; Akbulut, 1990). Incomplete gamma function of Wood was sufficient in describing lactation curve for Damascus goats. The Wood's model explained the variation quite accurately and described the shapes of lactation curves (Ayasrah et al., 2013). These models have been applied in diverse goat populations, including Alpine goats (González-Peña et al., 2012), Damascus goats in Jordan (Ayasrah et al., 2013), and crossbred goats in Saudi Arabia (Mousa and Elzarei, 2016). Each model offers unique advantages in terms of accuracy and applicability, depending on the production environment and specific traits of the studied population.

Protein and fat content in goat milk are also influenced by factors like lactation stage, season, and nutrition. Comparative studies on goat and cow milk proteins have highlighted significant differences due to species genetics and feeding practices (Haenlein, 2004; Min et al., 2005). Protein content, an important quality criterion for milk payment systems in many countries, is determined by lactation stage and season (Raynal-Ljutovac et al., 2005; Pirisi et al., 2007).

The aim of this study is to model changes in milk components during the lactation period of Damascus goats raised in Siirt, Türkiye. By focusing on Damascus goats in Siirt, the study also provides insights into local production dynamics, helping optimize goat milk yield and quality in the region. Specifically, the Wood and Ali-Schaeffer models, which are widely regarded as appropriate for describing lactation curves, were applied to protein and fat content data."By identifying the best-fitting model, this study seeks to elucidate the mathematical and biological relationships underlying these variations and analyze the connections between model parameters.

2. Materials and Methods

The animal material of this study consisted of 47 Damascus goats raised in Gökçebağ village of Siirt province. The animals were raised in extensive conditions and there were no special management practices for housing, feeding kidding etc. Milk samples were acquired every two weeks during the parturition season and 7 test days were performed in total (April 1-July 1, 2021). In total 274 test-day records were used in the study. The samples were brought to Siirt University, Faculty of Agriculture, Laboratory of Animal Husbandry with milk preservatives in 50 cc tubes and analyzed with Lactoscan Milk Analyzer (MILKOTRONIC LTD, Bulgaria) on the same day.

2.1. Mathematical Models

Wood and Ali-Schaeffer models are widely used lactation curve models. In this study, these mathematical models were applied to control day records. The models are as follows (Silvestre et al., 2006)

Wood $$Y_t = at^b e^{-ct} \tag{1}$$

Ali-Schaeffer $$Y_t = a + b\delta_t + c\delta_t^2 + d\theta_t + g\theta_t^2 \tag{2}$$

From the terms in equation 1,
Y_t : milk yield on day t of lactation (kg),
t : the time from kidding to the test day (days),
e: denotes the base of the natural logarithm.
a, b, c: parameter estimates of the lactation curve;
a: is an intercept,
b: curve increase at the beginning of lactation,
c: is the coefficient indicating the decline of the curve after reaching the highest level.
From the terms in equation 2,
$\delta_t = t/305$,
$\theta_t = \ln(305/t)$ and
t: indicates any day of lactation,
a: parameter refer to the peak yield,
d and g: parameters refer to the increase in the curve,
b and c: parameters refer to the decrease in the curve.

2.2. Comparison of the Models

The following criteria were used to compare the models (equation3-10) (Burnham and Anderson, 2002).

a) Coefficient of Determination,

$$R^2 = 1 - \sum_{i=1}^{n}(y_i - \tilde{y}_i)^2 / \sum_{i=1}^{n}(y_i - \bar{y})^2 \tag{3}$$

b) Adjusted Coefficient of Determination,

$$R^2_{adj} = 1 - (1 - R^2)\frac{n-1}{n-p} \tag{4}$$

c) Mean Squared Error (MSE),

$$MSE = \sqrt{\frac{1}{n-p}\sum_{i=1}^{n}(y_i - \tilde{y}_i)} \tag{5}$$

d) Wellmont Agreement Criteria

$$D = 1 - \frac{\sum(y_i - \tilde{y}_i)^2}{\sum\{|y_i - \bar{y}| + |\tilde{y}_i - \bar{y}|\}^2} \tag{6}$$

e) Mean Absolute Percentage Error (MAPE)

$$\bar{\varepsilon} = \frac{\sum_{i=1}^{n}\left|\frac{y_i - \tilde{y}_i}{y_i}\right|}{n} 100\% \tag{7}$$

f) Akaike Information Criterion

$$AIC = \ln\left[\frac{1}{n}\sum_{i=1}^{n}(y_i - \tilde{y}_i)^2\right] + \frac{2p}{n-(p+1)} \quad , \left(\frac{n}{p} < 40\right) \tag{8}$$

g) Bayesian Information Criterion

$$BIC = \ln\left[\frac{1}{n}\sum_{i=1}^{n}(y_i - \tilde{y}_i)^2\right] + \frac{p}{n}\ln n \tag{9}$$

h) Hannan-Quinn Information Criterion (HQC)

$$HQC = \ln\left[\frac{1}{n}\sum_{i=1}^{n}(y_i - \tilde{y}_i)^2\right] + \frac{2m}{n}\cdot[\ln(\ln n)] \qquad (10)$$

Where,
n : Number of observations,
p : Number of parameters in the model,
y_i : milk yield in the i[th] week,
$\bar{y}$: average daily milk yield,
$\tilde{y}$: the predicted milk yield.

In determining the best model, it was taken into consideration that the coefficient of determination, adjusted coefficient of determination and Wellmont Agreement Criterion were high, while the other criteria were low. In the study, R statistical package (R Core Team, 2021) was used to calculate the parameters in the models. The nlsLM() function from the minpack.lm package in R estimates model parameters using the Levenberg-Marquardt algorithm.

3. Results and Discussion

Means and standard errors of milk components according to control days are given in Table 1. Statistically significant differences were observed in milk components on individual control days (P<0.01), and this results highlighting the dynamic nature of milk composition throughout lactation). The findings revealed that milk fat content exhibited notable fluctuations, peaking at the end of the 1st and 3rd months, as well as at the beginning of the 4th month. This result is consistent with previous studies indicating that milk fat content varies due to physiological changes in lactation stages (Zeng and Escobar, 1995). Protein content started to increase at the end of the 1st month. The changes and distribution of milk components throughout the control period are given in Figure 1-9.

Table 1. Means and standard errors of milk components according to control days

N	Control day	Fat (%)**	SNF (%)**	Density**	Lactose (%)**	Salts (%)**	Protein (%)**	Freezing point**	pH**	EC**
1	01.04.2021	3.75±0.18^{a}	8.22±0.17^{cd}	29.09±0.56^{ef}	3.69±0.07^{de}	0.61±0.01^{d}	3.89±0.08^{de}	-0.46±0.01^{a}	6.69±0.02^{b}	6.44±0.17^{a}
2	22.04.2021	3.83±0.21^{a}	9.10±0.17^{ab}	32.45±0.61^{bc}	4.08±0.08^{ab}	0.67±0.01^{b}	4.31±0.08^{ab}	-0.51±0.01^{cd}	6.64±0.02^{c}	5.46±0.15^{b}
3	06.05.2021	2.47±0.18^{c}	9.27±0.29^{a}	35.17±0.65^{a}	4.26±0.08^{a}	0.71±0.01^{a}	4.49±0.08^{a}	-0.53±0.01^{d}	6.66±0.01^{bc}	5.24±0.13^{b}
4	19.05.2021	2.29±0.16^{c}	9.02±0.16^{ab}	33.36±0.60^{b}	4.04±0.07^{b}	0.67±0.01^{b}	4.27±0.08^{b}	-0.49±0.01^{bc}	6.63±0.02^{c}	5.47±0.12^{b}
5	03.06.2021	3.07±0.18^{b}	8.48±0.09^{cd}	30.65±0.37^{de}	3.81±0.04^{cd}	0.63±0.01^{cd}	4.02±0.04^{cd}	-0.47±0.01^{ab}	6.55±0.02^{d}	6.30±0.09^{a}
6	17.06.2021	3.65±0.17^{a}	8.72±0.16^{bc}	31.12±0.57^{cd}	3.91±0.07^{bc}	0.65±0.01^{bc}	4.13±0.07^{bc}	-0.49±0.01^{b}	6.65±0.02^{bc}	6.46±0.09^{a}
7	01.07.2021	3.77±0.18^{a}	8.08±0.09^{d}	28.57±0.31^{f}	3.61±0.04^{e}	0.60±0.01^{d}	3.83±0.04^{e}	-0.44±0.01^{a}	6.77±0.02^{a}	6.58±0.10^{a}

**P<0.01 (SNF: Non fat solids, EC: Electrical conductivity)

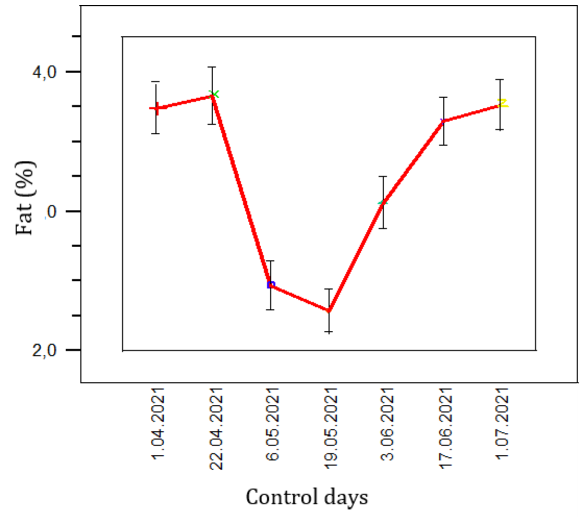

Figure 1. Variation of fat in milk.

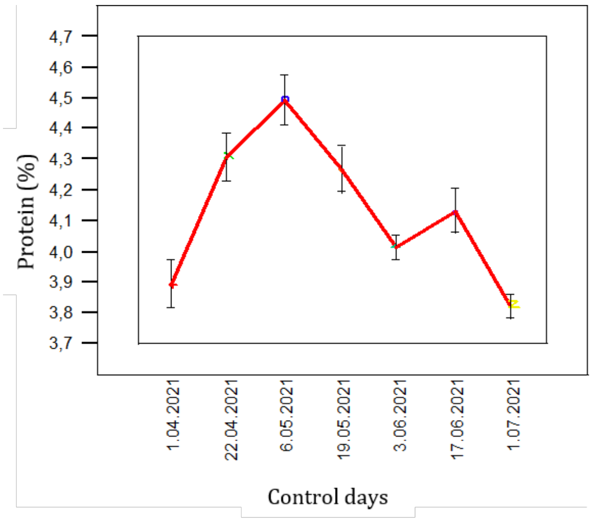

Figure 2. Variation of protein in milk.

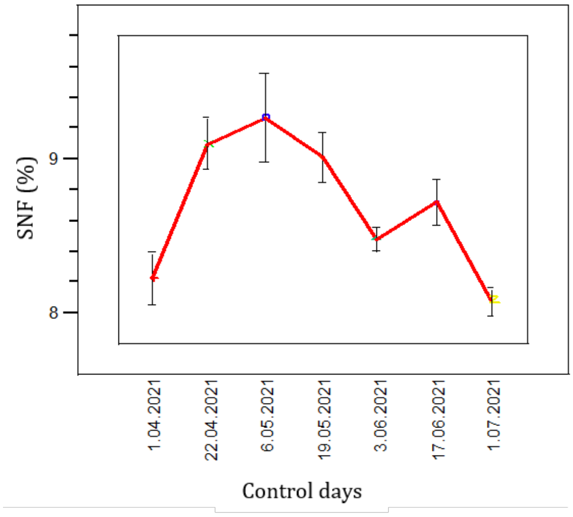

Figure 3. Variation of SNF in milk

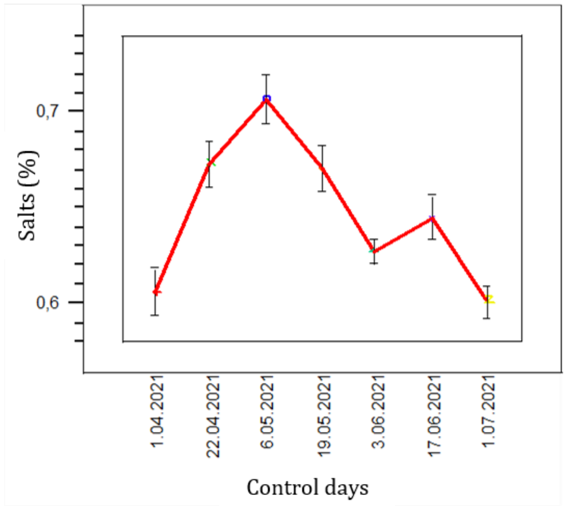

Figure 6. Variation of salts in milk

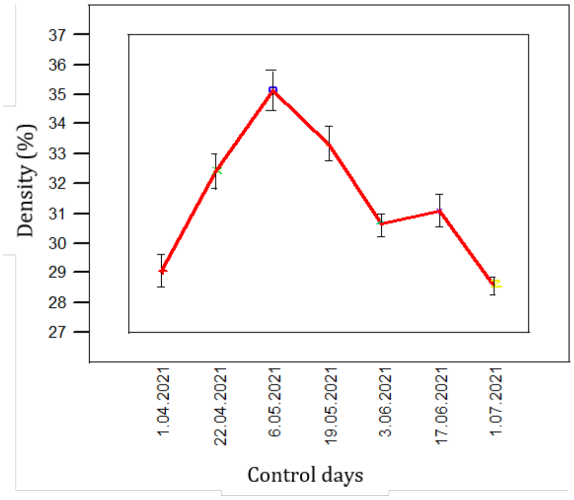

Figure 4. Variation of density in milk

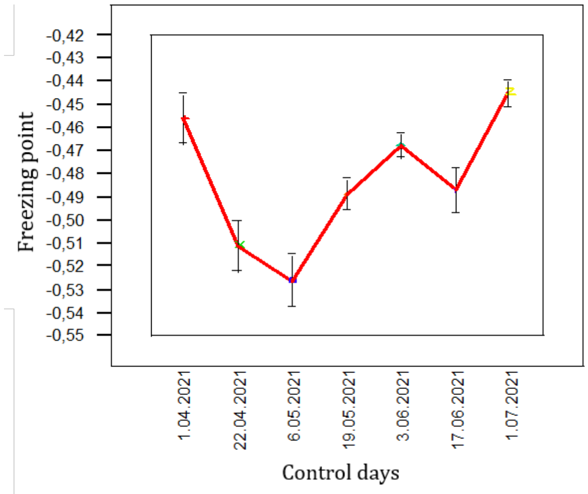

Figure 7. Variation of freezing point in milk

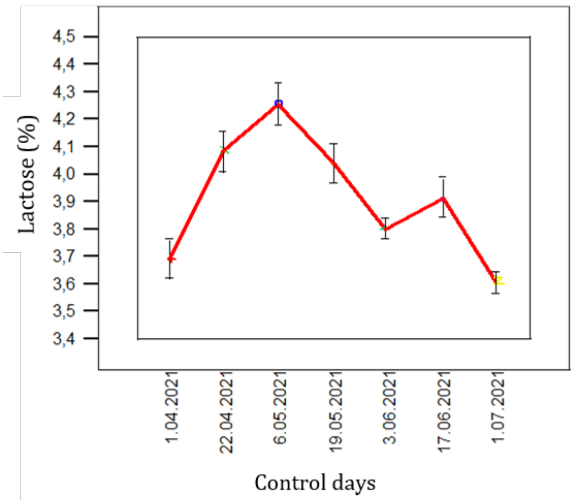

Figure 5. Variation of lactose in milk

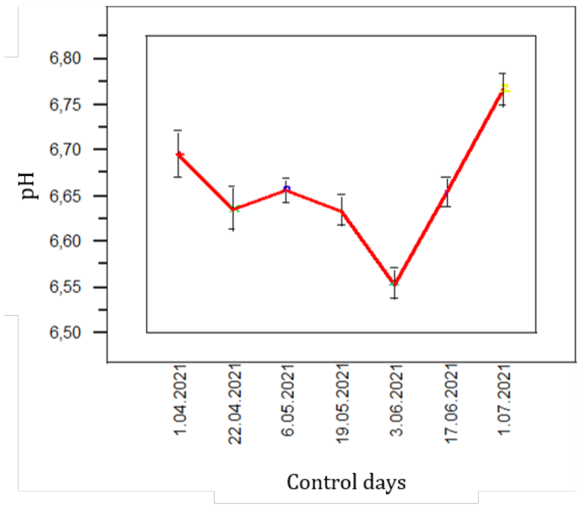

Figure 8. Variation of pH in milk

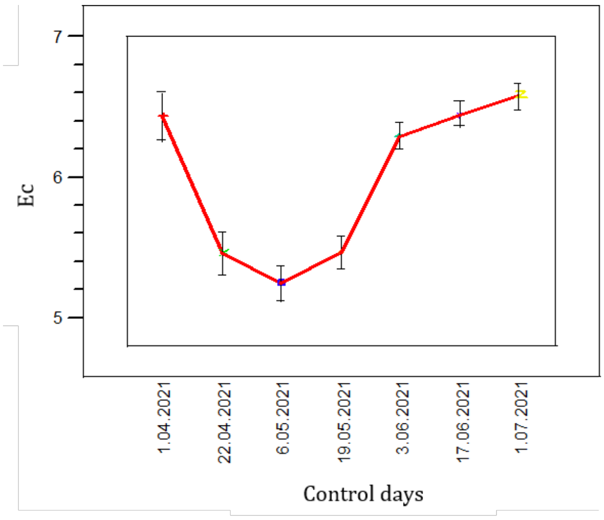

Figure 9. Variation of electrical conductivity in milk

The correlation between milk components is given in Table 2. When Table 2 is analyzed, the correlations of milk components with the others except the correlations with fat and pH were found to be statistically significant. Accordingly, there was a highly significant correlation between SNF and milk density, lactose, salt and protein (P<0.01) and a significant correlation between freezing point and electrical conductivity (P<0.05). There was no statistically significant correlation between milk fat content and other components. However, the correlation between milk protein content and density, lactose and salt was very significant (P<0.01). Zeng and Escobar (1995) reported that there was a significant correlation between milk fat content and SNF content in Alpine goats (P<0.001). In the same study, it was found that there was a significant correlation between milk lactose and protein content (P<0.05) and a very significant correlation between milk lactose content and SNF in accordance with the findings of the present study.

Table 2. Correlations between milk components

Milk components	Fat	SNF	Density	Lactose	Salt	Protein	Freezing point	pH
SNF	-0.570							
Density	-0.736	0.966**						
Lactose	-0.597	0.991**	0.982**					
Salt	-0.627	0.985**	0.988**	0.996**				
Protein	-0.597	0.990**	0.982**	0.999**	0.998**			
Freezing point	0.448	-0.972**	-0.933**	-0.983**	-0.973**	-0.983**		
pH	0.411	-0.453	-0.428	-0.421	-0.379	-0.407	0.385	
EC	0.634	-0.917**	-0.923**	-0.918**	-0.925**	-0.919**	0.873*	0.326

*P<0.05, **P<0.01

3.1. Fitting Lactation Curves

In the present study, Ali-Schaeffer and Wood models were applied to the data obtained for milk components. The parameters calculated as a result of the application of the models to the data are given in Table 3. In the Wood model, the coefficient a indicates the point where the curve crosses the y-axis, the coefficient b indicates the rise of the curve at the beginning of lactation and the coefficient c indicates the decline of the curve after reaching the highest level. In the Ali-Schaeffer model, the a parameter indicates the peak value, the d and g parameters indicate the rise in the curve, and the b and c parameters indicate the descent in the curve (Silvestre et al., 2006).

As can be seen from Table 3, the Ali-Schaeffer model has 5 parameters and the Wood model has 3 parameters. The graphs of the application of the Ali-Schaeffer and Wood models to the observation values are given in Supplementary Figures 1-18.

3.2. Model Comparison Results

When the models applied to the data obtained for milk components were evaluated with the comparison criteria, the changes in milk fat content, pH and electrical conductivity were best explained by the Ali-Schaeffer model, while the changes in SNF content, density, protein, lactose, salt and freezing point were better explained by the Wood model (Table 4). The curves fitted to the milk components are shown comparatively in the graphs between Figures 10-18.

Table 3. Calculated parameters of the models

Milk component	Models	Parameters				
		a	b	c	d	g
Fat	Ali-Schaeffer	-38.097**	43.315**	-1.472**	76.321**	-174.653**
	Wood	3.139**	-0.733	-0.231	-	-
SNF	Ali-Schaeffer	7.271	0.981	-0.033	-3.114	-9.808
	Wood	8.992**	0.245*	0.083**	-	-
Density	Ali-Schaeffer	82.348	-55.268	1.973	-118.704	191.116
	Wood	32.747**	0.362**	0.121**	-	-
Lactose	Ali-Schaeffer	5.216	-1.589	0.061	-5.174	3.113
	Wood	4.069**	0.270*	0.092*	-	-
Salts	Ali-Schaeffer	1.136	-0.552	0.021	-1.398	1.565
	Wood	0.669**	0.281*	0.095*	-	-
Protein	Ali-Schaeffer	5.772	-1.957	0.076	-5.995	4.227
	Wood	4.289**	0.267*	0.091*	-	-
Freezing point	Ali-Schaeffer	-0.291	-0.169	0.005	0.036	1.149
	Wood	-0.504**	0.256*	0.089*	-	-
pH	Ali-Schaeffer	9.979*	-3.426	0.143	-6.152	12.006
	Wood	6.635**	-0.034	-0.011	-	-
EC	Ali-Schaeffer	-9.056	16.117	-0.626	34.917	-51.823
	Wood	5.521**	-0.401*	-0.142*	-	-

*P<0.05, **P<0.01.

Table 4. Evaluation criteria for the models

Milk component	Model	p	R^2	R^2_{adj}	MSE	D	$\overline{\mathcal{E}}$	AIC	BIC	HQC
Fat	Ali-Schaeffer	5	0.99	0.99	0.01	0.99	1.06	53.45	-5.16	-5.59
	Wood	3	0.51	0.27	0.65	0.82	10.6	6.28	-0.88	-1.15
SNF	Ali-Schaeffer	5	0.88	0.63	0.39	0.97	1.29	56.19	-2.42	-2.85
	Wood	3	0.85	0.78	0.25	0.96	1.41	4.38	-2.79	-3.05
Densıty	Ali Schaeffer	5	0.90	0.69	1.86	0.97	1.81	59.29	0.68	0.25
	Wood	3	0.86	0.80	1.23	0.96	1.87	7.56	0.39	0.13
Lactose	Ali Schaeffer	5	0.86	0.57	0.21	0.96	1.68	54.96	-3.65	-4.09
	Wood	3	0.83	0.75	0.13	0.95	1.64	3.11	-4.06	-4.32
Salts	Ali Schaeffer	5	0.86	0.59	0.04	0.96	1.67	51.36	-7.25	-7.69
	Wood	3	0.82	0.74	0.02	0.95	1.75	-0.38	-7.55	-7.81
Protein	Ali Schaeffer	5	0.86	0.57	0.22	0.96	1.66	55.05	-3.56	-4.00
	Wood	3	0.83	0.74	0.14	0.95	1.67	3.23	-3.94	-4.20
Freezing point	Ali Schaeffer	5	0.81	0.44	0.03	0.95	2.05	51.09	-7.51	-7.95
	Wood	3	0.75	0.62	0.02	0.93	2.38	-0.60	-7.77	-8.03
pH	Ali Schaeffer	5	0.91	0.72	0.05	0.96	0.2	51.99	-6.61	-7.05
	Wood	3	0.46	0.19	0.07	0.77	0.53	1.77	-5.40	-5.66
EC	Ali Schaeffer	5	0.98	0.93	0.22	0.99	1.03	54.99	-3.63	-4.06
	Wood	3	0.84	0.76	0.33	0.95	3.05	4.91	-2.25	-2.52

p= number of parameters in the model, R^2= coefficient of determination, R^2_{adj}= adjusted coefficient of determination, MSE= mean squared error, D= Wellmont Agreement Criteria, $\overline{\mathcal{E}}$ = mean absolute percentage error, AIC= Akaike Information Criterion, BIC= Bayesian Information Criterion, HQC= Hannan-Quinn Information Criterion.

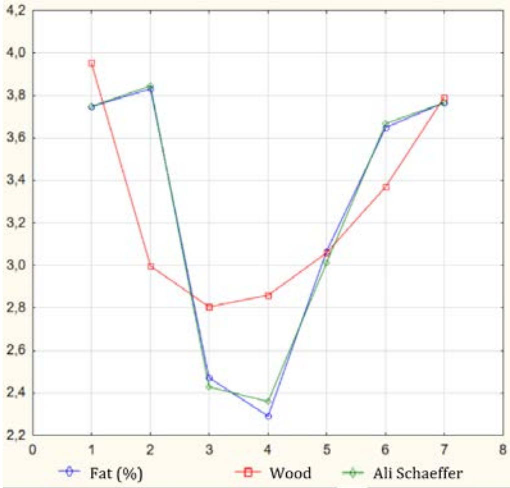

Figure 10. Plot of Ali-Schaeffer and Wood model fitting to fat content data

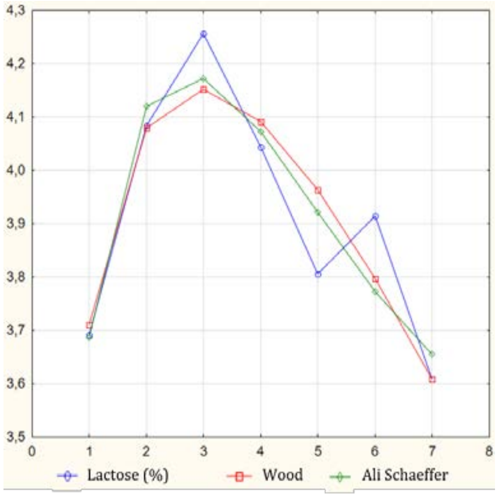

Figure 13. Plot of fitting Ali-Schaeffer and Wood models to lactose content data

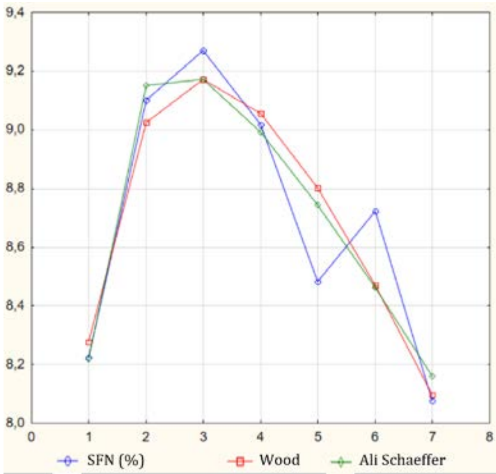

Figure 11. Plot of fitting Ali-Schaeffer and Wood models to the data for the SNF content

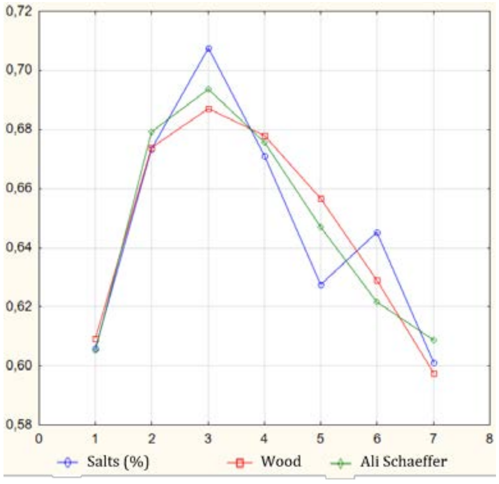

Figure 14. Plot of fitting Ali-Schaeffer and Wood models to salt content data

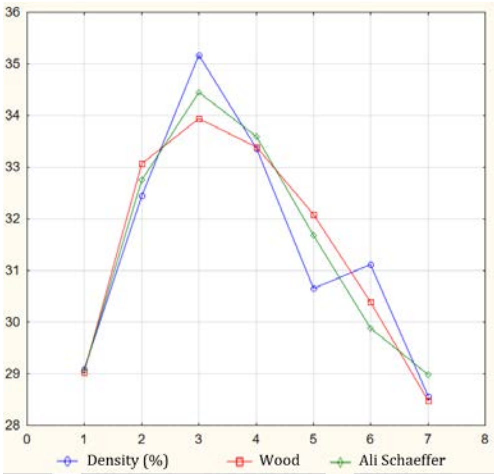

Figure 12. Plot of fitting Ali-Schaeffer and Wood models to density content data

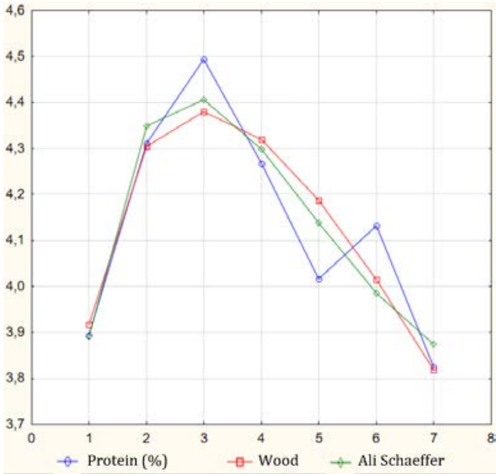

Figure 15. Plot of fitting Ali-Schaeffer and Wood models to protein content data

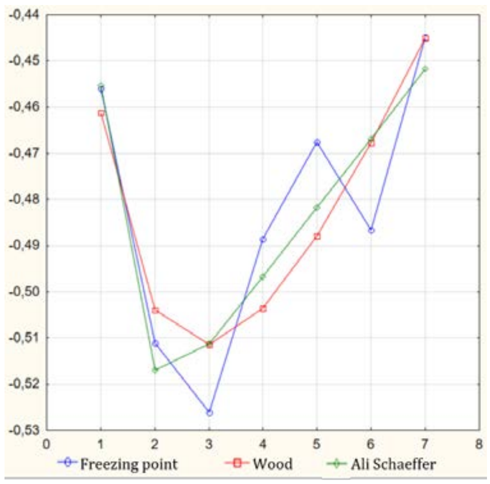

Figure 16. Plot of fitting Ali-Schaeffer and Wood models to freezing point data

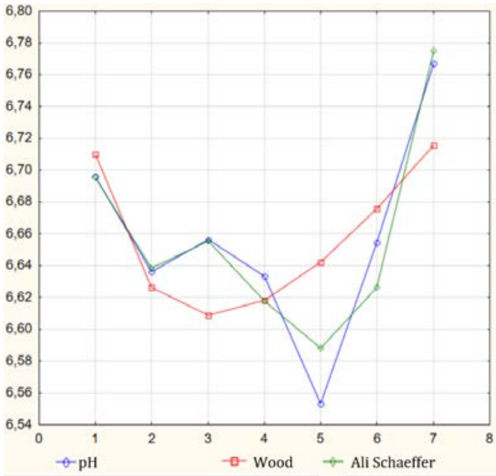

Figure 17. Plot of fitting Ali-Schaeffer and Wood models to pH data

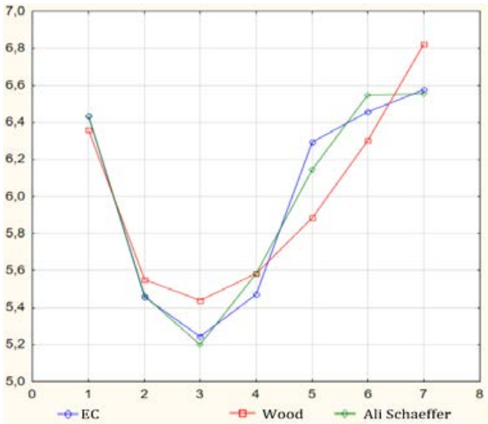

Figure 18. Plot of fitting Ali-Schaeffer and Wood models to EC data

Regarding lactation curve modeling, the comparison of Ali-Schaeffer and Wood models demonstrated varying performance across different milk components. The Ali-Schaeffer model, which includes five parameters, was found to better explain variations in milk fat, pH, and EC, likely due to its ability to capture complex fluctuations over time. In contrast, the Wood model, with its simpler three-parameter structure, provided a better fit for SNF, density, protein, lactose, salts, and freezing point. These results suggest that while the Wood model is effective for general trends, the Ali-Schaeffer model may be more suitable for components exhibiting pronounced early and late lactation variations.

5. Conclusion and Recommendations

In animal breeding, the prediction of some yields is of great importance in terms of breeding economics. Especially in economically important livestock, the time until the animals reach the productive age is an issue to be considered in terms of cost. This is an important issue in animal breeding applications and must be overcome. Therefore, the estimation method with mathematical models offers us benefits in terms of time and cost. In the case of determining the best prediction method, it will contribute to time and profitable production by making a good selection at the beginning, preparing a suitable ration considering the lactation curve and planning the appropriate strategies required by predicting the yield of the flock in advance. Most of the basic elements of lactation are similar in all species and especially between dairy goats and dairy cows, but there are some differences. Some of these are due to the higher metabolic rate in the goat.

In this study, two mathematical models commonly used in lactation curves were applied to milk components in the case of Damascus breed dairy goats, curves were drawn and parameters were calculated. The Wood and Ali-Schaeffer functions analyzed in the study were evaluated with AIC, BIC, HQC, MAPE, D, MSE, R^2_{adj} and R^2 methods used to compare different models, and the statistics obtained showed that different models gave better results in different components.

Author Contributions

The percentages of the authors' contributions are presented below. All authors reviewed and approved the final version of the manuscript.

	N.M.	A.Y	M.A.K.	F.C.	E.G.
C	40	20	20	10	10
D	50	30	20		
S	30	50	20		
DCP		30	40	20	10
DAI	100				
L	60			40	
W	60	20		20	
CR	60	20		20	
SR	50			50	
PM	30	30	30		10
FA	20	20	20	20	20

C= concept, D= design, S= supervision, DCP= data collection and/or processing, DAI= data analysis and/or interpretation, L= literature search, W= writing, CR= critical review, SR= submission and revision, PM= project management, FA= funding acquisition.

Conflict of Interest

The authors declared that there is no conflict of interest.

Ethical Consideration

Ethics committee approval was not required for this study because there was no study on animals or humans.

Acknowledgments

This study was supported by the Project No 2020-SİÜZİR-010 of the Scientific Research Council of Siirt University.

References

Akbulut Ö. 1990. Atatürk Üniversitesi Tarım İşletmesinde yetiştirilen Esmer, Esmer melezleri ile Siyah Alaca sığırların süt verim özellikleri ve laktasyon eğrisi parametrelerine etkili faktörler. Doktora Tezi, Atatürk Üniversitesi, Fen Bilimleri Enstitüsü, Erzurum, Türkiye, pp: 172.

Ayasrah EM, Abou-Bakr S, Ibrahim MAM. 2013. Characteristics of lactation curve in Damascus goats in Jordan. J Anim Poult Prod, 4(8): 479-491.

Burnham KP, Anderson DR. 2002. Model selection and multimodel inference. A practical information-theoretic approach. Springer-Verlag, New York, USA, 2nd ed., pp: 488.

Çilek S, Keskin İ, İlhan F, Hesna EŞ. 2009. Lactation curve traits of Anatolian population of Brown Swiss cows in Turkey. Archiva Zootechnica, 15(2): 53-60.

Çilek S, Keskin I. 2008. Comparison of six different mathematical models to the lactation curve of Simmental cows reared in Kazova State Farm. J Anim Vet Advan 7: 1316-1319.

Dağ B, Keskin İ, Zülkadir U, Boztepe S. 2003. Çumra Ziraat Meslek Lisesinde yetiştirilen esmer ineklerin süt verim özellikleri ve bu özelliklere ait tekrarlanma dereceleri. Selcuk J Agr Food Sci, 17(1): 13-17.

Daşkıran İ, Yılmaz A, Günbey VS. 2022. A study on lactation milk yield and milk qualtiy characteristics of Kilis goats in farm conditions. J Tekirdag Agri Fac, 19(03): 678-687.

FAO. 2014. FAOSTAT. URL: https://www.fao.org/faostat/en/#data (accessed date: September 11, 2024).

Gaddour A, Najari S, Ferchichi A. 2009. Lactation curve of local goat, pure breds and crosses in southern Tunisia. J Appl Anim Res, 36(1), 153-157.

Gök T, Mikail N, Akkol S. 2019. Analysis of the first lactation curve in Holstein cows with different mathematical models. KSU J Agric Nat, 22(4): 601-608.

González-Peña D, Acosta J, Guerra D, González N, Acosta M, Sosa D, Torres-Hernández G. 2012. Modeling of individual lactation curves for milk production in a population of Alpine goats in Cuba. Livest Sci, 150(1-3), 42-50.

Groenewald PC, Viljoen CS. 2003. A Bayesian model for the analysis of lactation curves of dairy goats. J Agri Biol Env Stat, 8, 75-83.

Haenlein GFW. 2004. Goat milk in human nutrition. Small Rumin Res, 51, 155-163.

Kaymakçı M, Engindeniz S. 2010. Türkiye'de Keçi Yetiştiriciliği; Sorunlar ve Çözümler. Ulusal Keçicilik Kongresi Tam Metin Bildiri Kitabı, 24 Haziran, Çanakkale, Türkiye, pp: 1-25.

Keskin İ, Dağ B, Sariyel V. 2009a. Fitness of four different mathematical models to the lactation curve of Brown Swiss cows in Konya Province of Turkey. Can J Anim Sci, 89(2): 195-199.

Keskin İ, Çilek S, İlhan F. 2009b. Polatlı tarım işletmesinde yetiştirilen Siyah Alaca siğirlarin laktasyon eğrisi özellikleri. Kafkas Üniv Vet Fak Derg, 15(3): 437-442.

Keskin İ, Tozluca A. 2004. Süt sığırlarında laktasyon eğrilerinin farklı matematik modellerle belirlenmesi ve kontrol aralığının tespiti. SÜ Zir Fak Derg, 18(34): 11-19.

Madsen OA. 1975. Comparison of some suggested measures of persistency of milk yield in dairy cows. Anim Prod, 20: 191-197.

Masselin S, Sauvant D, Chapoutot P, Milan D. 1987. Les modèles d'ajustement des courbes de lactation. Ann Zootech, 36: 171-206.

Min BR, Hart SP, Sahlu T, Satter LD. 2005. The effect of diets on milk production and composition, and on lactation curves in pastured dairy goats. J Dairy Sci, 88: 2604-2615.

Mousa E, Elzarei MF. 2016. Prediction of lactation curve in Saudi Arabia, Damascus and their crossbred goats. J Agri Vet Sci, 267(3724), 1-22.

Paksoy M. 2007. Kahramanmaraş ilinde süt üretimine yönelik keçi yetiştiriciliğine yer veren tarım işletmelerinin ekonomik analizi. Doktora Tezi, Ankara Üniversitesi, Fen Bilimleri Enstitüsü, Ankara, Türkiye, pp: 157.

Park YW, Haenlein GFW. 2006. Overview of milks of minor species. In: Park YW, Haenlein GFW. Editors, Handbook of Milk of Non-Bovine Mammals. Blackwell Publishers. Ames, Iowa and Oxford, England, pp: 3-10.

Pirisi A, Lauret A, Dubeuf JP. 2007. Basic and incentive payments for goat and sheep milk in relation to quality. Small Rumin Res, 68: 167-178.

R Core Team 2021. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL: https://www.R-project.org/ (accessed date: September 11, 2024).

Raynal-Ljutovac K, Gaborit P, Lauret A. 2005. The relationship between quality criteria of goat milk, its technological properties and the quality of the final products. Small Ruminant Res, 60: 167-177.

Raynal-Ljutovac K, Lagriffoul G, Paccard P, Guillet I, Chilliard YY. 2008. Composition of goat and sheep milk products: An update. Small Ruminant Res, 79(1): 57-72.

Semerci A, Çelik AD. 2016. Türkiye'de küçükbaş hayvan yetiştiriciliğinin genel durumu. Mustafa Kemal Üniversitesi Zir Fak Derg, 21(2): 182-196.

Silvestre A, Petim-Batista F, Colaço J. 2006. The accuracy of seven mathematical functions in modeling dairy cattle lactation curves based on test-day records from varying sample schemes. J Dairy Sci, 89: 1813-1821.

Tüfekçi H. 2023. Keçi sütü üretimi ve önemi. Osmaniye Korkut Ata Üniversitesi Fen Bil Ens Derg, 6(1): 970-981.

Wood PDP. 1967. Algebraic model of lactation curve in cattle. Nature, 218: 164-165.

Yadav KA, Singh J, Yadav KS. 2016. Composition, nutritional and therapeutic values of goat milk: A review. Asian J Dairy Food Res, 35(2): 96-102.

Zeng SS, Escobar, EN. 1995. Effect of parity and milk production on somatic cell count, standard plate count and composition of goat milk. Small Ruminant Res, 17: 269-274.

Zülkadir U, Aytekin İ, Keskin İ. 2008. Relationship between persistency values defined with various methods and some lactation traits of Brown Swiss cattle in Turkey. J Applied Anim Res, 34(1): 137-141.

Black Sea Journal of Agriculture

doi: 10.47115/bsagriculture.1571516

Open Access Journal
e-ISSN: 2618 – 6578

Research Article
Volume 8 - Issue 2 : 143-151 / March 2025

INTEGRATED MANAGEMENT OF *Meloidogyne incognita* ON TOMATO USING COMBINATIONS OF COMMERCIAL ABAMECTIN AND PLANT ACTIVATOR

Fatma Gül GÖZE ÖZDEMİR[1]*, Harun ÇİMENKAYA[1]

[1]Isparta University of Applied Sciences, Faculty of Agriculture, Department of Plant Protection, 32200, Isparta, Türkiye

Abstract: One of the main pests of tomatoes is root knot nematodes and causes significant yield losses. The abamectin is a bio-based pesticide and plant activators is used stimulating systemic acquired resistance mechanisms. Determining their suppressive effects on nematodes and understanding their interactions may be important for better use in integrated management. The effect of abamectin (*Streptomyces avermitilis*, Abamax®) and plant activators (harpin and *Lactobacillus acidiophilus*) singly or in combination was tested against *Meloidogyne incognita* on tomato under controlled conditions. The experiment was established 5 days after transplanting of 35 days of tomatoes. ProAct Plus® (Harpin, 0.15 g/l), ISR-2000® (*L. acidophilus*, 1 ml/l) and Crop-Set® (*L. acidophilus*, 0.6 ml/l) were applied to the leaves by spraying, while Abamax® was applied to the soil. Nematode inoculation (1000 second juvenile larvae (J2)) was planned 72 hours after the first application of activators. The activators were applied to tomatoes 2 more times with 14 days intervals. After sixty days, plant height and fresh weight, root height and fresh weight, number of galls and egg masses, gall index, J2 soil density and lignification of leaves, stem and roots were evaluated. While the gall index was 4/0-5 index in plants treated only with nematodes, it was found to be 1.2/0-5 index in Abamax®. While 1.6 was found in Proact Plus®, 2.0 was detected in ISR2000® and Cropset®. No galls or egg masses were found in ProAct Plus®±Abamax®, ISR-2000®±Abamax® and Crop-Set®±Abamax®. The positive effect of abamectin alone on plant development was found to be higher than plant activators. Root fresh weight increased significantly in abamectin and plant activator combinations. Plant activators caused an increase in lignification and the highest level was found in Proact Plus®. Lignification was higher in combinations with abamectin. The highest lignification was in Abamax®±Proact Plus®. Combinations of harpin and *L. acidophilus* activators with abamectin may be a potential antagonism strategy against root-knot nematodes.

Keywords: Abamectin, *Meloidogyne incognita*, Plant activators, Harpin, *Lactobacillus acidiophilus*

***Corresponding author:** Isparta University of Applied Sciences, Faculty of Agriculture, Department of Plant Protection, 32200, Isparta, Türkiye
E mail: fatmagoze@isparta.edu.tr (F.G. GÖZE ÖZDEMİR)
Fatma Gül GÖZE ÖZDEMİR https://orcid.org/0000-0009-0001-3211-2045
Harun ÇİMENKAYA https://orcid.org/0000-0003-1969-4041

Received: October 21, 2024
Accepted: December 04, 2024
Published: March 15, 2025

Cite as: Göze Özdemir FG, Çimenkaya H. 2025. Integrated management of meloidogyne incognita on tomato using combinations of commercial abamectin and plant activator. BSJ Agri, 8(2): 143-151.

1. Introduction

Root-knot nematodes belong to the genus *Meloidogyne*, which has more than 98 species (Jones et al., 2013). Among them, *Meloidogyne incognita, Meloidogyne javanica, Meloidogyne arenaria* and *Meloidogyne hapla* represent 95% of the populations of all root-knot nematode species (Dong et al., 2012). They sensitize the plants to other pathogens and stress factors (Kyndt et al., 2013). Due to their fixed endoparasitic, wide host range, high reproductive rate and short life cycle, control of root knot nematode is more difficult than other plant pathogens (Quentin et al., 2013). The use of fumigants and nematicides is common in root knot nematode control. However, these pose a serious risk to both the environment and human health due to misuse, overuse and long persistence in soil and groundwater, which can adversely affect all food chains (Ntalli et al., 2011, Azlay et al., 2022). In recent years, studies have focused on environmentally friendly alternative controls that can help control root-knot nematode without harming non-target organisms (Degenkolb and Vilcinskas, 2016). Biological control is the most effective alternative found to date for the control of root-knot nematode and has potential for integrated pest management (Kumar and Arthurs, 2021). In integrated pest and disease control methods, there has been an increased interest induced resistance in biological control (Saravanakumar et al., 2007). The induced resistance is the stimulation of the plant's defense mechanisms by a biotic or abiotic factors and induced resistance can be expressed as the activation of passive resistance mechanisms in the plant, not the creation of a non-existent resistance (Van Loon et al., 1998). Resistance is realized by recognizing and activating the elicitor molecules of the pathogen and promoting oxidative reaction, lignification, hypersensitive response, PR proteins and any of the changes in plant metabolism (Chaube and Pundhir, 2005, Barutçu, 2006). Plant activators are defined as "substances that activate the natural defense systems of plants, enable them to make better use of nutrients, help to protect them from stress conditions and similar external factors and factors, and/or have natural and/or chemical strengthening, resistance-enhancing, soil structure-regulating properties that positively affect yield and product quality and carry one or more of these properties together". Plant activators enable plants to show resistance against diseases by stimulating Systemic Acquired Resistance (SAR) mechanisms (Durrant and Dong, 2004).

Harpins are naturally occurring proteins from a novel group of compounds first reported from *Erwinia amylovora* (Wei et al., 1992). Harpin proteins, including harpinEα and harpinαβ, elicit the expression of genes involved in the hypersensitive response, enhancement of plant growth and activate an induced systemic defense response (Wei and Beer, 1996). This response has been associated with increased resistance to pathogens and some other pests in plants. As a result of these discoveries, commercial plant activator products containing harpin proteins such as Messenger®, N-HIBITTM®, Mighty PlantTM® and ProActTM® have been developed (Kirkpatrick et al., 2006). In Türkiye, the bioactivator whose active ingredient is harpin was previously available in the market as Messenger®, but is now sold as ProAct® (Şener, 2015). Infection with *M. incognita* was induced in cotton cultivars in which transgenically expressed harpinEa constructs (PE58) were created, compared to the susceptible cultivar. In each experiment, selected transgenic cultivars produced on average 56% to 62% fewer eggs and 72% to 81% fewer J2 compared to the susceptible control cultivar Coker (French et al., 2006). Kirkpatrick et al. (2006) applied 2 harpin proteins (EBC-151ST and EBC-152) in cotton by seed spraying and 1 by foliar spraying (EBC-351A), resulting in less root rot and fewer *M. incognita* eggs and J2 on average compared to control plants. In multi-location field trials conducted in Minnesota (MN), a sensitive cultivar (Pioneer 91M70) treated with N-Hibit HX-209® was found to have 4% higher yields than untreated plants (Lisa et al., 2007). In contrast, field trials in Iowa using seeds coated with N-Hibit HX-209® found no effect on yield and soybean cyst nematode (SCN) egg population at the end of the season (Tylka and Marett, 2008).

Lactic acid bacteria (LAB) also have antagonistic activity against pathogenic bacteria and fungi, making them ideal for developing biocontrol agents for use in plants (Trias et al., 2008; Jang et al., 2011; Guarner et al., 2012; Lim et al., 2018). Compounds such as organic acids, hydrogen peroxide, bacteriocins and lipid and amino acid metabolites produced by LAB are among the antimicrobial factors (Kormin et al., 2001). Nowadays, LAB attract great attention in the agricultural industry as an alternative to problems such as antibiotic resistance and pesticide residues. It is known that *Lactobacillus* species act as an antagonistic agent and exhibit antimicrobial activity (Hamed et al., 2011). However, there are not many studies on the nematicidal activity of *Lactobacillus* spp. on phytopathogenic nematodes. Seo et al. (2019) found that *L. brevis* was effective on root-knot nematodes. Crop-Set® is Türkiye's first licensed activator and the first natural plant activator with an organic license. It contains *L. acidiophilus* liquid fermentation product, plant extract, manganese sulfate, iron sulfate and copper sulfate. Crop-Set® increases the plant's ability to utilize nutrients in an environmentally safe way, thereby optimizing fruit and vegetable yields and improving quality and uniformity. With its bacteriocins and organic acids, it stimulates the plant immune system and increases plant resistance in the fight against harmful microorganisms (Şener, 2015). ISR-2000 is a fermentation product of *L. acidophilus* and contains yucca plant extract, yeast extract, riboflavin, benzoic acid, nicotinamide and thiamine. ISR-2000® increases the activity of enzymes such as chitinase, gluconase and peroxidase in the plant. After the stimulation occurs, the plant remains at the highest level of alert against a possible subsequent attack and thus can best defend itself against pathogenic invasion (Tosun and Ergün, 2002, Koca, 2003). *Lactobacillus acidophilus* is a gram (±), rod-shaped, non-spore forming lactic acid bacteria (Suraporn et al., 2015; Urmann et al., 2016). It was found that the nematode *Caenorhabditis elegans* when fed with *L. acidophilus*, *Enterococcus faecalis* and *Staphylococcus aureus* infections prevented (Kim and Mylonakis, 2012).

Abamectin is one of the alternative biocathional mediators belonging to the avermectin group of macrocyclic lactone metabolites produced by natural fermentation of *Streptomyces avermitlis* bacteria. Abamectin is used as insecticides, acaricides and nematicides in vegetables, fruits and field crops (Khalil, 2013). The mode of action of avermectins is to block the transmission of electrical activity in nerves and muscle cells by stimulating the release and binding of gamma-amino butyric acid (GABA) at nerve endings (Roder and Stair, 1998). This causes an influx of chloride ions into the cells (activating or opening the glutamate-gated chloride channel), which leads to hyperpolarization and subsequent paralysis of neuromuscular systems (Cully et al., 1994; Burkhart, 2000) and subsequent death. In nematodes, GABA receptors are found in neuromuscular and central ventral ganglia. GABA has also been reported in second juvenile (J2) larvae of *Globodera rostochiensis* and *M. incognita* (Stewart et al., 1994). Seed, soil and foliar applications of abamectin were found to have suppressive effects on nematodes. Seed treatment with abamectin reduced J2 penetration into roots, resulting in lower colonization and reproduction of *M. incognita* in cotton and cucumber plants (Becker et al., 2006; Bessi et al., 2010). Abamectin (Vertemic 1.8% EC) has proven its nematicidal activity as a soil application suppressing root-knot nematodes on different vegetable crops (Hamida et al., 2006; Khalil, 2012; Saad et al., 2012). In addition, it was effective against *Ditylenchus dipsaci* in garlic, reducing nematodes per cm[2] tissue (Becker, 1999).

In this study, the effects of single abamectin and plant activators (containing harpin and *L. acidophilus*) application and combinations with each other on the infection of root-knot nematode, *M. incognita* in tomato, plant growth parameters and plant ligninization were investigated under controlled conditions.

2. Materials and Methods

2.1. Materials

Harpin 3% WG (ProAct Plus®, AMC-TR) and *L. acidiophilus* fermented content ISR-2000® (Alltech Crop Science) and Crop-Set® (Alltech Crop Science) plant activators and abamectin (Abamax 50 SC®, Rotam) were used in the study. Plant activators and abamectin were purchased commercially. The study will be conducted with 35 days old Özkan F1 tomato seedlings which susceptible root knot nematode. The ISP root knot nematode isolate, which was pure cultured and morphologically identified in previous studies (Göze et al., 2022).

2.2. Mass production of root-knot nematode

Mass production was carried out with 15 plants under controlled conditions (24±1 °C, 60%±5% humidity). The J2s were obtained from the pure cultivated tomato roots by removing the egg masses under a stereo binocular microscope using the petri method. Previously, 1000 J2s were inoculated in 1000 microliters of water by making small holes in the soil near the root collar of each of the Tueza F1 tomato seedlings that were transplanted in pots. Plastic pots with a volume of 250 ml and sterile soil mixture containing 68% sand, 21% silt and 11% clay were used. Mass production was terminated 8 weeks after inoculation.

2.3. Preparation of nematode inoculum

After washing the roots of Tueza F1 tomato variety in tap water, egg masses were taken from the roots under stereo microscope and incubated in a petri dish in water at 25±2°C for three days. After three days, J2s emerging from the eggs were counted under a light microscope (Göze Özdemir et al., 2022) and 1000 J2s placed in 1 ml tubes (Özdemir and Gözel, 2017).

2.4. Pot experiments

This study, which was carried out to induce resistance in tomato plants by using plant activators alone and in combination with abamectin and to investigate the possibility of using it in the control of root-knot nematodes, consisted of 9 applications (Table 1). The study was established in a randomized plots experimental design with 5 replications for each application. Each replicate was planted with 1 Özkan F1 tomato seedling. The seedlings were transplanted into 250 ml plastic pots containing 300 g of sterile soil mixture (68% sand, 21% silt and 11% clay). The experiment was established 5 days after transplanting. ProAct Plus®, ISR-2000® and Crop-Set® were applied to the leaves by spraying, while Abamax was applied to the soil. The dosage of plant activators was prepared by using the label information. The recommended dose was set at 0.15 g/l for ProAct Plus®, 1 ml/l for ISR-2000® and 0.6 ml/l for Crop-Set®. The activators used in the application were applied to tomato plants 2 more times with 14 days intervals after the first application date of the activators as specified in the label information (Şener, 2015). The application was carried out 3 times in total until the experiment ended. Nematode inoculation was planned 72 hours after the first application of activators as a spray on plant leaves. A thousand of *M. incognita* J2 with 1 ml of water were inoculated into holes drilled near the root of tomato in pot. Plants with only nematode inoculation and plants without nematode inoculation were used as controls. Additionally, no activator was applied to plants without nematode inoculation.

Table 1. The applications of experiment

1	ProAct Plus® alone
2	ISR-2000® alone
3	Crop-Set® alone
4	Abamax® alone
5	ProAct Plus®± Abamax®
6	ISR-2000®±Abamax®
7	Crop-Set®± Abamax®
8	Nematode (+) Control
9	Nematode Free (-) Control

The experiment was terminated 60 days after nematode inoculation. Afterwards, the plants height and fresh weight measured, roots remove the soil and washed with clean water. Then, root height and root fresh weight values were taken. Later, the number of gall and egg masses in the roots were counted under stereo microscope. Evaluation was done 0-5 scale (0= no gall, 1= 1-2 gall, 2= 3-10 gall, 3= 11-30 gall, 4=31-100 gall, 5= more than 100 gall).

SPSS (version 20.0) program was used for statistical analysis of the data obtained as a result of the experiment, and analysis of variance (ANOVA) was performed to test the differences between the means. Means were compared by Tukey HSD test at $P \leq 0.05$.

2.5. Determination of Lignin Synthesis

Lignin accumulation in leaves, roots and stem parts of tomato plants, in which resistance was promoted by the application of plant activators, was determined by phloroglucinol/hydrochloric acid (HCl) test (Şener, 2015).

In pot experiments, the treated tomato plants were removed from the pots without damaging the root zone and washed with water. Certain tissues were taken from the roots, stems and leaves of these plants. The chlorophylls in the infected tissues were removed in 100% methanol containing 1% phloroglucinol at room temperature (20°C) for 1 night. The whitened tissue samples were kept in chloral hydrate (2.5 g/ml) for at least 24 hours to make the tissues transparent.

Chlorophyll was removed with the help of methanol and the tissues cleaned with chloral hydrate were placed on a sterile slide and 1-2 drops of concentrated HCl solution was added and kept for 10 minutes. At the end of the waiting period, a few drops of 50% glycerol solution were added on the tissues and the coverslip was closed. The covered coverslips were examined under a light microscope. Since the stained tissues lost their color within 3-5 hours, the samples were examined under a light microscope immediately after staining. It was observed that 10 minutes after HCl was added to the infected tissues, the lignified structures turned a dark pink color (Şener, 2015).

3. Results

The number of galls, number of egg masses, gall index and J2 density in the soil of control plants treated with nematodes only were significantly higher than all treatments ($P \leq 0.05$). The number of galls and egg masses in the roots of Abamax® treated plants were lower than Cropset®, ISR2000® and Proact® application. When the plant activators were compared among themselves, the lowest number of gall and egg masses was found in Proact® application. The number of gall and egg masses in ISR2000® application was higher than Cropset® application. In the combinations of plant activators with Abamax®, gall and egg masses were not detected in the roots. While the highest J2 density in soil was determined in the nematode control, J2 density decreased significantly in single and combination treatments ($P \leq 0.05$). However, there was no significant difference ($P \leq 0.05$) between applications in terms of J2 density in soil (Table 2).

There was no statistically significant difference in gall index between Cropset®, ISR2000®, Proact® and Abamax® application ($P \leq 0.05$). While gall index was lower in combination application than single application, there was no statistically significant difference in gall index between ISR2000® ± Abamax®, Cropset® ± Abamax®, and Proact® ± Abamax®combination applications ($P \leq 0.05$). Although the suppressive effects of plant activators alone on the nematode were determined, the control effect was significantly increased in combination with Abamax® (Table 2).

The lowest plant height was found only in the nematode treated control plants. When compared to the plants without nematode inoculation, plant height decreased significantly. The highest plant height was found in Abamax® application. Plant height was lower in Cropset®, ISR2000® and Proact® applications than Abamax application. In addition, there was no statistical difference ($P \leq 0.05$) in plant height when the combination applications with Abamax® were compared with single. Compared to the nematode control, single applications of Cropset®, ISR2000® and Proact® had positive effects on plant height. However, the effect of Abamax® application alone was found to be high on plant height, while plant height was found to be lower in combination applications (Table 3).

The lowest plant fresh weight was found only in nematode treated plants. The highest plant fresh weight was found in Proact® application. Plant fresh weight of ISR2000® application was lower than Proact® and Cropset® applications. Abamax® combination of ISR2000® treatment had a positive effect on plant fresh weight. There was no statistically significant difference in plant fresh weight between the combinations of Cropset® and Proact® with Abamax® and single applications (Table 3).

When the plant activators were evaluated among themselves in the root length parameter, there was no significant difference between them ($P \leq 0.05$). Root length values of plant activators applied alone were found to be similar to Abamax® application. Although there was a numerical increase in root length values in combinations of plant activators with Abamax®, there was no statistically significant difference between them ($P \leq 0.05$). However, when compared with the nematode control, Abamax®, Cropset® ± Abamax® and Proact® ± Abamax® treatments had a positive effect on root length (Table 3).

Compared to the nematode control, root fresh weight was higher in Abamax® and combination treatments. Root fresh weight was higher in Cropset® treatment than ISR2000® and Proact® treatment. Plant activators had a positive effect on root fresh weight when applied together with Abamax®. The effect of Abamax® on root fresh weight was higher than that of plant activators applied alone (Table 3).

Table 2. Effect of applications on the development of *Meloidogyne incognita* on tomato root (Mean±Std. Error)

Application	Number of galls/root	Number of Egg masses/root	Soil J2 Density (100 g soil)	Gal Index(0-5)
Cropset®	4.6±0.7^{ab*}	4.3±0.5^{c}	18.0±5.8^{b}	2.0±0.0^{b}
ISR2000®	7.2±0.8^{b}	5.2±0.6^{b}	12.0±7.3^{b}	2.0±0.0^{b}
Proact®	1.2±0.3^{bc}	0.2±0.2^{e}	4.0±2.4^{b}	1.6±0.4^{b}
Abamax®	0.6±0.2^{bc}	0.6±0.2^{d}	2.0±2.0^{b}	1.2±0.4^{b}
Cropset®±Abamax®	0.0±0.0^{c}	0.0±0.0^{e}	0.0±0.0^{b}	0.0±0.0^{c}
ISR2000®±Abamax®	0.0±0.0^{c}	0.2±0.2^{e}	0.0±0.0^{b}	0.0±0.0^{c}
Proact®±Abamax®	0.0±0.0^{c}	0.0±0.0^{e}	2.0±2.0^{b}	0.0±0.0^{c}
Nematode (+) Control	47.2±2.4	42.8±2.7^{a}	55.6±60.7^{a}	4.0±0.0^{a}
Nematode-free (-) Control	0.0±0.0^{c}	0.0±0.0^{c}	0.0±0.0^{b}	0.0^{c}

*The lowercase letters in the same column indicate statistically differences between applications ($P \leq 0.05$).

Table 3. Effect of Applications on Tomato Plant Growth Parameters (Mean±Std. Error)

Application	Plant Height	Plant Fresh Weight	Root Height	Root Fresh Weight
Cropset®	33.9±1.29^{b*}	12.1±1.2^{ab}	17.7±0.7^{ab}	3.5±0.1^{abc}
ISR-2000®	34.3±1.3^{b}	8.2±0.7^{b}	16.8±1.5^{ab}	2.8±0.2^{bc}
Proact®	34.0±1.1^{b}	11.3±0.8^{a}	18.1±1.0^{ab}	2.6±0.1^{c}
Abamax®	43.8±1.1^{a}	12.0±0.9^{ab}	19.1±0.8^{a}	3.9±0.1^{ab}
Cropset±Abamax	33.4±1.1^{b}	12.0±0.9^{ab}	19.5±1.1^{a}	4.0±0.4^{a}
ISR2000®±Abamax®	33.6±1.2^{b}	11.0±1.1^{ab}	16.3±0.6^{ab}	4.5±0.3^{a}
Proact®±Abamax®	33.6±1.1^{b}	13.4±0.9^{ab}	20.0±0.8^{a}	4.0±0.1^{a}
Nematode (+) Control	24.4±1.5^{c}	3.6±0.2^{c}	13.6±0.6^{b}	2.5±0.2^{c}
Nematode-free (-) Control	33.9±1.7^{b}	10.9±0.9^{ab}	15.7±1.1^{ab}	2.7±0.1^{c}

*The lowercase letters in the same column indicate statistically differences between applications (P≤0.05).

As a result of the examination of stained root, stem and leaf tissues of tomato plants, differences in lignification distribution and density were observed. Lignified structures were identified as having turned a dark pink color. The plant activator with the highest lignin staining was found to be Proact® (Figure 1), followed by ISR-2000® and Crop-Set®. In the applied plant activators, lignin accumulation was determined to be highest in leaves, stems and roots, respectively. Lignification was detected to be higher in combinations with Abamectin. The highest lignification was detected in the Abamectin and Proact combination application (Figure 2).

Figure 1. Lignification in the leaf (a) and stem (b) in Proact® application.

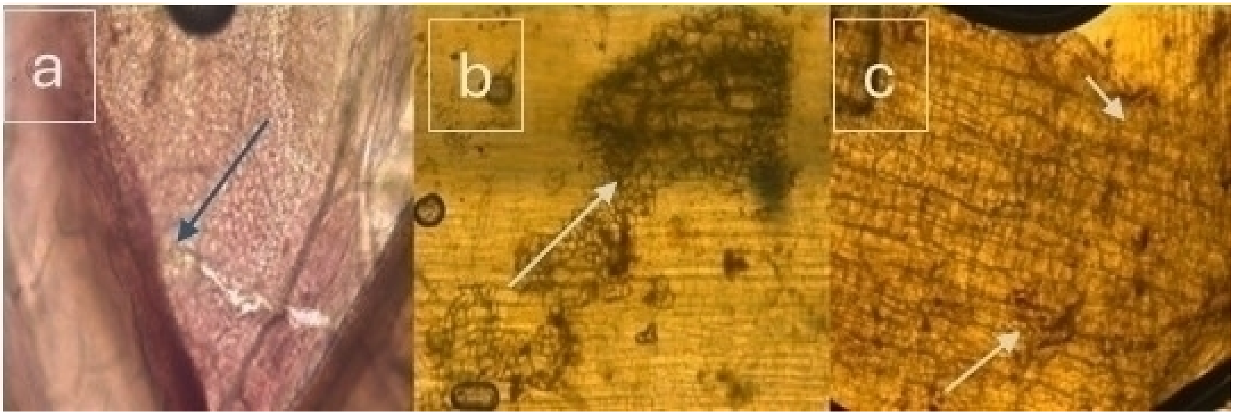

Figure 2. Lignification in the leaves (a), stems (b) and roots (c) in Abamax® and Proact® combination applications.

4. Discussion

In the study, it was determined that the application of Abamax® (abamectin) commercial preparation to the soil significantly suppressed *M. incognita* in the roots of tomatoes and had a positive effect on plant development. It is a good alternative to the fumigant methyl bromide, whose use is banned all over the world, and most carbamates and organophosphates. Abamectin is an effective nematicide recorded to control plant parasitic nematodes such as *Meloidogyne* spp., *Heterodera* spp., *Pratylenchus penetrans*, *Globodera pallida, Rotylenchulus reniformis* and *Tylenchulus semipenetrans* in different crops (Li et al., 2018; Sasanelli et al., 2020a; Massoud et al., 2023). Different studies have shown that abamectin causes an increase in plant and root system length and weight (Korayem et al., 2008; Qiao et al., 2012).

Abamectin (Vertemic 1.8% EC) has proven its nematicide effectiveness in suppressing root-knot nematodes on different vegetable crops as a soil application (Hamida et al., 2006; Khalil, 2012; Saad et al., 2012). It is stated that abamectin formulations are an important factor in biological activity against plant parasitic nematodes (Li et al., 2018). Sasanelli et al. (2020b) reported that abamectin had higher toxicity than fluopyram to the J2 of root knot nematode but the control effect of abamectin (1.8% EC, 375 g a.i./ha) was significantly lower than that of fluopyram (41.7% SC, 450 a.i./ha) in both pot and field trials. Abamectin activates glutamate-gated chloride channels, which open to allow chloride ions to enter the cell, ultimately causing hyperpolarization. This causes paralysis of the neuromuscular system and death (Cully et al., 1994). In addition, abamectin only causes sublethal toxicity in mice or other mammals at very high concentrations. However, subchronic and chronic toxic effects for low doses and long-term exposure are still unclear (Bai and Ogbourne, 2016). Low rates of accumulation over a long period of time can be highly toxic to fish and can enter the human body as part of the biological food chain (Qiu et al., 2022).

Another result of the study is that plant activators can be used in the control against root knot nematode. Although no difference was determined between plant activators in terms of gall index, a difference was found between them in terms of the number of galls and egg masses. The number of galls and egg masses in the roots was found to be lower in the Proact® (Harpin) application than in the Cropset® (*L. acidophilus*) and ISR-2000® (*L. acidophilus*) applications. As a result of dyeing studies on sections taken from the roots, stems and leaves of plants, it was determined that lignifacition increased in plants to which activator was applied and it is thought that durability was promoted. It has been shown that the continuity of resistance is ensured with fourteen-day applications. Resistance occurs as oxidative combustion, lignification or hypersensitive response when the elicitor molecules of the pathogen are recognized and activated (Chaube and Pundhir, 2005). SAR is a physiological condition that occurs with biotic or abiotic environmental stimuli that activate a plant's immune defenses (Vallad and Goodman, 2004). Plants exhibiting SAR have enhanced resistance to various pathogens. SAR can be induced by challenging a plant with lethal, harmful, and non-pathogenic microorganisms or artificially with certain chemicals (Sticher et al., 1997; Gozzo, 2003). Many compounds have been shown to be SAR elicitors, such as salicylic acid, 2,6-dichloro-isonicotinic acid (INA), benzo(1,2,3)thiadiazole-7-carbotioic acid S-methyl ester (BTH, known as acibenzolar-S-methyl) and the microbial protein harpin (Klessig et al., 2000). Collins et al. (2006) stated that BTH (acibenzolar S methyl) and harpin applications reduced the number of lesion nematodes (*Pratylenchus* spp.) in potatoes, while BTH reduced *M. chitwoodi* at the end of the season. In addition, potatoes treated with BTH and high dose harpin reduced the nematode infection index and the number of discarded potatoes by 26% compared to the control. Harpin is preferably used as foliar application and at 14-day intervals during plant vegetation. When applied to a plant, harpin proteins bind to plant receptors and stimulate many biochemical reactions through gene activation, and the resistance mechanism in the plant becomes active (Akbudak and Tezcan, 2006). Seo et al. (2019) found that *L. brevis* WiKim0069 showed the strongest nematicidal activity against the J2 of *M. incognita, M. arenaria,* and *M. hapla* in vitro. The fermentation broth of WiKim0069 also reduced gall formation on melon under field conditions, with a higher efficacy (62.8%) than that of fosthiazate (32.8%). Treatment with various *Lactobacillus* strains can also improve the innate immunity of plants through a systemic acquired resistance, resulting in the upregulation of defense-related metabolites and leading to resistance to phytopathogens (Hamed et al., 2011; Konappa et al., 2016).

In combination applications, galls and egg masses could not be found in the roots. Combination applications of abamectin and plant activators have been shown to be promising in the future, with both nematode suppression and increase in plant development. While there are studies on abamectin in combination with different chemical and biological agents, no studies were found with plant activators. Shaver et al., (2016) reported that abamectin combined with azoxystrobin had a good control effect on *Trichodorus obtusus* Cobb in Zoysia grass. The control efficacy of the combined treatment was higher than that of 1,3-D used alone and the tomato yields were increased (Qiao et al., 2014). Khalil (2013) conducted a pot trial to evaluate the effect of abamectin, *Bacillus thuringiensis* and *Bacillus subtilis*, alone or in combination, against the development of *M. incognita* in tomato plants and found that abamectin had the highest rate of reducing gall formation by 85.87%. The second most effective application was found to be abamectin ± *B. thuringiensis* (85.20%). The combination of abamectin ± *B. thuringiensis* recorded the highest increase in root length and root fresh weight. The combination of abamectin with *Purpurecillium lilacinum* and rhizobacteria was the most effective against *M. incognita*, also effective in increasing tomato plant growth parameters compared to the control (El-Ashry et al., 2021). In this study, although there was an increase in the plant and root development parameters of single applications and combination applications compared to plants with only nematode inoculation, a similarity was found between them when compared with plants without nematode inoculation and any application. No significant increase in plant and root development parameters was detected in combination applications

5. Conclusion

A root-knot nematode management strategy using plant activators will meet the world's growing demand for environmentally friendly agent that can replace synthetic chemicals and toxic pesticides in agriculture. By using abamectin once and supporting it with plant activators throughout the season, yield loss can be reduced and possible toxicological problems of abamectin can be minimized. The application of various bioagents including abamectin might be a potential antagonism strategy against root knot nematodes in protected agricultural areas. Additionally, these studies need to be supported by field studies.

Author Contributions

The percentages of the authors' contributions are presented below. All authors reviewed and approved the final version of the manuscript.

	F.G.G.	H.Ç.
C	50	50
D	50	50
S	50	50
DCP	40	60
DAI	80	20
L	20	80
W	50	50
CR	50	50
SR	40	60
PM	60	40
FA	50	50

C= concept, D= design, S= supervision, DCP= data collection and/or processing, DAI= data analysis and/or interpretation, L= literature search, W= writing, CR= critical review, SR= submission and revision, PM= project management.

Conflict of Interest

The authors declared that there is no conflict of interest.

Ethical Consideration

Ethics committee approval was not required for this study because there was no study on animals or humans.

Acknowledgments

The study was supported the TUBITAK (BİDEB) 2209-A University Students Research Projects Program in 2023/1. We would like to thank in this program for supporting the study.

References

Akbudak N, Tezcan H. 2006. Bitkisel üretimde ve bitki korumada yeni bir etken madde: Harpin. Uludağ Üniv Zir Fak Derg, 20(2): 39-43.

Azlay L, El Boukhari MEM, Mayad EH, Barakate M. 2022. Biological management of root-knot nematodes (*Meloidogyne* spp.): a review. Organic Agri, 2022: 1-19.

Bai SH, Ogbourne S. 2016. Eco-toxicological effects of the avermectin family with a focus on abamectin and ivermectin. Chemosphere, 154: 204-214.

Barutçu E. 2006. Domateste patates Y virüsü (PVY) dayanıklılığının genetiği. Yüksek Lisans Tezi, Pamukkale Üniversitesi, Fen Bilimleri Enstitüsü, Biyoloji Anabilim Dalı, Denizli, Türkiye, ss: 65.

Becker JO, Becker JS, Morton HV, Hofer D. 2006. Early protection against root-knot nematodes through nematicidal seed coating provides season-long benefits for cucumbers. Cucurbitaceae, Asheville, North Carolina, USA, pp: 395- 402.

Becker WF. 1999. The effect of abamectin on garlic infected by *Ditylenchus dipsaci*. Nematologia Brasileira 23(2): 1-8

Bessi R, Sujimoto FR, Inomoto MM. 2010. Seed treatment affects *Meloidogyne incognita* penetration, colonization and reproduction on cotton. Ciênc Rural, 40: 1428-1430.

Burkhart CN. 2000. Ivermectin: an assessment of its pharmacology, microbiology and safety. Vet Hum Toxicol, 42: 30-35

Chaube HS, Pundhir VS. 2005. Crop diseases and their management. PHI Learning Pvt. Ltd., New Delhi, India, pp: 724.

Chukwudebe AC, Feely WF, Burnett TJ, Crouch LS, Wislocki PG. 1996. Uptake of emamectin benzoate residues from soil by rotational crops. J Agric Food Chem 44: 4015-4021.

Collins HP, Navare DA, Riga E, Pierce FJ. 2006. Effect of foliar applied plant elicitors on microbial and nematode populations in the root zone of potato. Commun Soil Sci Plant Analysis, 37(11-12): 1747-1759.

Cully DF, Vassilatis DK, Liu KK, Paress PS, Van der ploeg LH, et al. 1994. Cloning of an avermectin-sensitive glutamate-gated chiloride channel from *Caenorhabditis elegans*. Nature, 371: 707-711

Degenkolb T, Vilcinskas A. 2016. Metabolites from nematophagous fungi and nematicidal natural products from fungi as an alternative for biological control. Part I: metabolites from nematophagous ascomycetes. Applied Microbiol Biotechnol, 100: 3799-3812.

Dong L, Huang C, Huang L, Li X, Zuo Y. 2012. Screening plants resistant against *Meloidogyne incognita* and integrated management of plant resources for nematode control. Crop Protect, 33: 34-39.

Durrant WE, Dong X. 2004. Systemic acquired resistance. Annu Rev Phytopathol, 42: 185-209.

El-Ashry RM, Ali MA, Elsobki AE, Aioub AA. 2021. Integrated management of *Meloidogyne incognita* on tomato using combinations of abamectin, *Purpureocillium lilacinum*, rhizobacteria, and botanicals compared with nematicide. Egyptian J Biological Pest Control, 31, 1-10.

French NM, Rock L, Kirkpatrick ARTL, Hope AR, Wei Z, Bothell WA. 2006. Harpınea Gene Transgenıc Cotton Reduces Reproductıon By Root Knot Nematodes. Beltwide Cotton Conferences, San Antonio, Texas - January 3 – 6.

Gozzo F. 2003. Systemic acquired resistance in crop protection: from nature to a chemical approach. J agricultural and food chemistry, 51(16): 4487-4503.

Göze Özdemir FG, Tosun B, Şanlı A, Karadoğan T. 2022. Bazı Apiaceae uçucu yağlarının *Meloidogyne incognita* (Kofoid & White, 1919) Chitwood, 1949 (Nematoda: Meloidogynidae)'ya karşı nematoksik etkisi. Ege Üniversitesi Ziraat Fakültesi Dergisi, 59(3): 529-539.

Guarner F, Khan AG, Garisch J, Eliakim R, Gangl A, Thomson A, Krabshuis J, Lemair T, Kaufmann P, de Paula JA, Fedorak R, Shanahan F, Sanders M E, Szajewska H, Ramakrishna BS, Karakan T, Kim N. and World Gastroenterology Organization. 2012. World Gastroenterology Organisation global guidelines: probiotics and prebiotics October (2011). J. Clin.

Gastroenterol. 46:468-481
Hamed HA, Moustafa YA, Abdel-Aziz SM. 2011. In vivo efficacy of lactic acid bacteria in biological control against *Fusarium oxysporum* for protection of tomato plant. Life Sci. J. 8:462-468.
Hamida AO, El-Gindi AY, Hoda HA, Youssef MM, Asmahan ML. 2006. Evaluation of the nematicidal effects of a biotechnological product (Abamectin) on *Meloidogyne incognita*, root-knot nematode infecting cowpea plants. Pakistan J Nematol, 24: 75-79.
Jang SE, Hyun YJ, Oh YJ, Choi KB, Kim T, Yeo IH, Han MJ, Kim DH. 2011. Adhesion activity of *Lactobacillus plantarum* PM 008 isolated from kimchi on the intestine of mice. J Bacteriol Virol, 41: 83-90.
Jansson RK, Rabatin S. 1998. Potential of foliar, dip, and injection applications of avermectins for control of plant-parasitic nematodes. J Nematology, 30(1): 65.
Jones J T, Haegeman A, Danchin EG, Gaur HS, Helder J, Jones MG, Perry RN. 2013. Top 10 plant-parasitic nematodes in molecular plant pathology. Molec Plant Pathol, 14(9): 946-961.
Khalil MS. 2012. A comparison study with alternative biorational agents to suppress the root-knot nematode populations and galls formation in tomato plants. Inter J Nematol, 22: 112-116.
Khalil MS. 2013. Abamectin and azadirachtin as eco-friendly promising biorational tools in integrated nematodes management programs. J. Plant Pathol Microbiol, 4(4): 1-7.
Kim Y, Mylonakis E. 2012. *Caenorhabditis elegans* immune conditioning with the probiotic bacterium *L. acidophilus* strain NCFM enhances gram positive immune responses. Infect Immunity, 80: 2500– 2508.
Kirkpatrick TL, Hope AR, Lawrence KS, Lawrence GW, Mueller JD, Blackville SC, French NM. 2006. Greenhouse evaluation of experimental harpin-based seed and foliar treatments on root knot nematodes in cotton. Beltwide Cotton Conferences, January 3 - 6, San Antonio, Texas, USA, pp: 30-35.
Klessig DF, Durner J, Noad R, Navarre DA, Wendehenne D, Kumar D, Silva H. 2000. Nitric oxide and salicylic acid signaling in plant defense. Proceede National Acad Sci, 97(16): 8849-8855.
Koca YO. 2003. İki bitki aktivatörünün patateste bazı tarımsal özellikler üzerine etkileri. Yüksek Lisans Tezi, Ege Üniversitesi, Fen Bilimleri Enstitüsü, Tarla Bitkileri Anabilim Dalı, İzmir, Türkiye, ss: 55.
Konappa NM, Maria M, Uzma F, Krishnamurthy S, Nayaka SC, Niranjana SR, Chowdappa S. 2016. Lactic acid bacteria mediated induction of defense enzymes to enhance the resistance in tomato against *Ralstonia solanacearum* causing bacterial wilt. Scientia Horticult, 207: 183-192.
Korayem AM, Mahmoud MAY, Moawad MMM. 2008. Effect of chitin and abamectin on *Meloidogyne incognita* infesting rape seed. J Plant Prot Res, 48: 365-370.
Kormin S, Rusul G, Radu S. Ling FH. 2001. Bacteriocin-producing lactic acid bacteria isolated from traditional fermented food. Malays J Med Sci, 8: 63-68.
Kumar KK, Arthurs S. 2021. Recent advances in the biological control of citrus nematodes: a review. Biol Cont, 157: 104593.
Kyndt T, Vieira P, Gheysen G, de Almeida-Engler J. 2013. Nematode feeding sites: unique organs in plant roots. Planta, 238: 807-818.
Li B, Ren Y, Zhang D, Xu S, Mu W, Liu F. 2018. Modifying the formulation of abamectin to promote its efcacy on southern root-knot nematode (*Meloidogyne incognita*) under blending-of-soil and root-irrigation conditions. J Agric Food Chem, 66: 799–805.
Li X, Wang X, Zhang S, Liu D, Duan Y, Dong W. 2012. Identification of soybean microRNAs involved in soybean cyst nematode infection by deep sequencing. PloS One, 7(6): e39650.
Lim JH, Yoon SM, Tan PL, Yang S, Kim SH, Park HJ. 2018. Probiotic properties of *Lactobacillus plantarum* LRCC5193, a plant-origin lactic acid bacterium isolated from kimchi and its use in chocolates. J Food Sci, 83:2802-2811
Lisa M, Breitenbach FR, Miller RP. 2007. The effect of N-Hibit seed treatment on soybean yield at Kasson MN. 2007. University of Minnesota-Extension. Available at: http://www.extension.umn.edu/agriculture/cropsresearch/south/2007/docs/2007-n-hibit-seed-treatment-soybean.pdf. (accessed date: September 10, 2020).
Massoud MA, Saad AFS, Khalil MS, Zakaria M, Selim S. 2023. Comparative biological activity of abamectin formulations on root-knot nematodes (*Meloidogyne* spp.) infecting cucumber plants: in vivo and in vitro. Sci Rep, 13(1): 12418.
Ntalli NG, Ferrari F, Giannakou I, Menkissoglu-Spiroudi U. 2011. Synergistic and antagonistic interactions of terpenes against *Meloidogyne incognita* and the nematicidal activity of essential oils from seven plants indigenous to Greece. Pest Manag Sci, 67(3): 341-351.
Omura S, K Shiomi. 2007. Discovery, chemistry, and chemical biology of microbial products. Pure Appl Chem, 79: 581-591.
Ozdemir E, Gozel U. 2017. Efficiency of some plant essential oils on root-knot nematode *Meloidogyne incognita.* J Agri Sci Tech A, 7(3): 178-183.
Qiao K, Liu X, Wang H, Xia X, Ji X, et al. 2012. Effect of abamectin on root-knot nematodes and tomato yield. Pest Manag Sci, 68: 853-857.
Qiao K, Duan HM, Wang HY, Wang Y, Wang KY, Wei M. 2014. The efficacy of the reduced rates of 1,3-D + abamectin for control of *Meloidogyne incognita* in tomato production in China. Sci Horticult, 178:248–252.
Qiu D, Xu N, Zhang Q, Zhou W, Wang Y, Zhang Z, Qian H. 2022. Negative effects of abamectin on soil microbial communities in the short term. Front Microbiol, 13: 1053153.
Quentin M, Abad P, Favery B. 2013. Plant parasitic nematode effectors target host defense and nuclear functions to establish feeding cells. Front Plant Sci, 4: 53.
Roder JD, Stair EL. 1998. An overviev of ivermectin toxicosis. Vet Hum Toxicol, 40: 369-370
Saad ASA, Massoud MA, Ibrahim HS, Khalil MS. 2012. Activity of nemathorin, natural product and bioproducts against root-knot nematodes on tomatoes. Arch Phytopathol Plant Prot, 45: 955-962.
Saravanakumar D, Charles VN, Kumarb R. 2007. PGPR-induced defense responses in the tea plant against blister blight disease. Crop Prot, 26: 556-565.
Sasanelli N, Toderas I, Veronico P, Iurcu-Straistaru E, Rusu S, Melillo MT, Caboni P. 2020a. Abamectin efficacy on the potato Cyst nematode *Globodera pallida*. Plants, 9(1).
Sasanelli N, Toderaş I, Iurcu-Straistaru E, Bivol A, Rusu Ş, Konrat A, Andoni C. 2020b. In vitro effect of abamectin from *Streptomyces avermitilis* on the survival of the cyst nematodes *Globodera pallida, Heterodera carotae* and *Heterodera schachtii*. Series B, Horticulture, 64(1): 1-11.
Seo HJ, Park AR, Kim S, Yeon J, Yu NH, Ha S, Kim JC. 2019. Biological control of root-knot nematodes by organic acid-producing *Lactobacillus brevis* wikim0069 isolated from kimchi. Plant Pathol J, 35(6): 662.
Shaver BR, Agudelo P, Martin S B. 2016. Use of abamectin and azoxystrobin for managing stubby-Root nematode (*Trichodorus obtusus* Cobb) damage to zoysiagrass. Crop Sci,

56: 1330–1336.

Stewart GR, Perry RN, Wright DJ. 1994. Immunocytochemical studies on the occurrence of gamma-aminobutyric acid (GABA) in the nervous system of the nematodes *Panagrellus redivivus, Meloidogyne incognita* and *Globodera rostochiensis.* Fund App Nematol, 17: 433-439.

Sticher L, Mauch-Mani B, Métraux AJ. 1997. Systemic acquired resistance. Annu Rev Phytopathol, 35(1): 235-270.

Stiles ME, Holzapfel WH. 1997. Lactic acid bacteria of foods and their current taxonomy. Int J Food Microbiol, 36: 1-29

Suraporn S, Sangsuk W, et al. 2015. Effects of probiotic bacteria on the growth parameters of the Thai silkworm, *B. mori*. Thai J Agri Sci, 48 (1): 29-33.

Sener C. 2015. Bazı bitki aktivatörlerinin biberde patates Y virüsüne karşı etkilerinin belirlenmesi. Doktora Tezi, Bursa Uludağ Universitesi, Bursa, Türkiye, ss: 92.

Tosun N, Ergün A. 2002. Bitkisel üretimde ve tarimsal savaşimda yeni bir yaklaşim olarak bitki aktivatörlerinin rolü. Tarım ve Köyişleri Bakanlığı Ege Tarımsal Araştırma Enstitüsü Müdürlüğü Yayın No: 109, TATEK/TYUAP Tarımsal Araştırma Yayım ve Koordinasyonu 2002 Yılı Tarla Bitkileri Grubu Bilgi Alışveriş Toplantısı Bildirileri, Ankara, Türkiye, ss: 251-263.

Trias R, Bañeras L, Montesinos E, Badosa E. 2008. Lactic acid bacteria from fresh fruit and vegetables as biocontrol agents of phytopathogenic bacteria and fungi. Int Microbiol, 11: 231-236.

Tylka G, Marett C. 2008. Field testing of N-HibitTM seed treatment in Iowa. Available at: http://crops.extension.iastate.edu/cropnews/2008/05/field-testing-nhibit%E2%84%A2-seed-treatment-iowa (accesed date: March 12, 2023).

Urmann K, Arshavsky-Graham S, Walter JG, Scheper T, Segal E. 2016. Whole-cell detection of live *Lactobacillus acidophilus* on aptamer-decorated porous silicon biosensors. Analyst, 141: 5432-5440

Vallad GE, Goodman RM. 2004. Systemic acquired resistance and induced systemic resistance in conventional agriculture. Crop Sci, 44(6): 1920-1934.

Van Loon LC, Bakker PAHM, Pieterse CMJ. 1998. Systemic resistance induced by rhizosphere bacteria. Annu Rev Phytopathol, 36(1): 453-483.

Wei Z, Beer V. 1996. Harpin from *Erwinia amylovora* induces plant resistance. Act Hort, 411: 221-224.

Wei Z, Laby RL, Zumoff CH, Nauer DW, He SY, Collmer A, Beer SV. 1992. Harpin, elicitor of the hypersensitive response produced by the plant pathogen *Erwinia amylovora*. Sci, 257: 85-88.

Black Sea Journal of Agriculture
doi: 10.47115/bsagriculture.1601603

Open Access Journal
e-ISSN: 2618 – 6578

Research Article
Volume 8 - Issue 2 : 152-157 / March 2025

INVESTIGATING THE POTENTIAL OF COMBINING CATTLE WASTE WITH SWITCHGRASS AND SUGAR BEET LEAVES FOR BIOGAS PRODUCTION

Cevat FİLİKCİ[1]*, Tamer MARAKOĞLU[2]

[1]*Kırşehir Ahi Evran University, Çiçekdağı Vocational School, Department of Plant and Animal Production, 40700, Kırşehir, Türkiye*
[2]*Selçuk University, Faculty of Agriculture, Department of Agricultural Machinery and Technologies Engineering, 42130, Konya, Türkiye*

Abstract: This research aimed to determine the biogas potential produced as a result of different mixtures of cattle waste (CW), three different Switchgrass (SG) (*Panicum virgatum* L.) and beet leaves (BL). In the study, a laboratory-scale setup was established to determine the biogas potential. The experimental design used in this study consisted of three treatment groups. Biogas measurements were taken until the end of biogas production of the materials and recorded on computer at. In the first experimental group, biogas yields of all materials were determined separately. In the second experimental group, cattle waste (CW) (1:1 ratio) was mixed with other materials. It was observed how much the amount of gas produced by the cattle waste, which was kept constant, increased as a result of the mixture with which material, and the Switchgrass (*Panicum virgatum* L.) plant, which provided the highest yield, was selected. Then, in the third experimental group, the cattle waste (CW) was kept constant at fifty percent and different mixtures of Switchgrass (*Panicum virgatum* L.) plant and beet leaves were formed. It was revealed in which mixture the highest biogas yield was obtained. In the study, it was observed that the biogas yield rate of cattle waste was higher than the other materials within the framework of the literature information and the extent to which Switchgrass plants and beet leaves increased the biogas yield. During the measurements, the temperature and pH values were checked periodically and the mixing process was carried out by hand shaking every day. The experimentals were carried out considering a 10% dry matter rate. The highest biogas yield was found to be 3504.07 mL g DM^{-1} of CW (Cattle Waste) at the end of the 30^{th} day in the 1st experimental group. Biogas yield values for the other materials in the 1^{st} experimental group were determined as BL 2148 mL. gDM^{-1} , SG1 (Kanlow) 1971.4 mL.gDM^{-1} , SG2 (Shawne) 1058.4 mL g DM^{-1} and SG3 (Alamo) 822.5 mL.g DM^{-1} , respectively. In the 2^{nd} experimental group, after the gas outflows stopped at the end of the 16^{th} day, the highest biogas yield was determined as 707.82 mL.gDM^{-1} in the CW-SG1 mixture. In the 3^{rd} experimental group, at the end of the 43^{rd} day, a total of 1997.5 mL.gDM^{-1} was determined in the CW (50%)- SG (20%)- BL (30%) mixture.

Keywords: Biogas, Biomethane, Lignocellulosic biomass, Sugar beet leaf, Sustainable energy

***Corresponding author:** Kırşehir Ahi Evran University, Çiçekdağı Vocational School, Department of Plant and Animal Production, 40700, Kırşehir, Türkiye
E mail: cevat.filikci@ahievran.edu.tr (C. FİLİKCİ)
Cevat FİLİKCİ https://orcid.org/0000-0002-4169-8412
Tamer MARAKOĞLU https://orcid.org/0000-0002-2824-116X
Received: December 14, 2024
Accepted: January 15, 2025
Published: March 15, 2025
Cite as: Filikci C, Marakoğlu T. 2025. Investigating the potential of combining cattle waste with switchgrass and sugar beet leaves for biogas production. BSJ Agri, 8(2): 152-157.

1. Introduction

Energy requirements is increasing with the technological developments in the world and in our country. As a result of this growing need in recent years, humanity has turned to different energy systems. The fact that exhaustible energy sources (oil, natural gas, coal, etc.) are unable to meet the need and harm the environment supports this trend. Along with renewable energy sources, has a move towards methods of obtaining energy that provide different and continuous use.

Developed countries are increasing, expanding energy diversity and continuing their search for alternative energy by trying to reduce dependence on certain types of energy sources. Biofuels are one of the most important new and rapidly expanding alternative sources (Eser et al., 2007).

Türkiye is negatively affected by the fact that 92% of our oil needs are met through imports and our economy is dependent on imports. This is a problem for all countries at risk in terms of energy security. In this context, the development of agriculture-based biofuels such as biodiesel, bioethanol, biomass and biogas attracts attention worldwide (Christian and Elbersen, 1998). Switchgrass was designated as a model plant among 37 species in the United States due to its utility as a feed source and its significant bioenergy potential. The cultivation of switchgrass is promoted for energy and animal feed production owing to its high net energy yield per unit area, low cultivation costs, low ash content, high water use efficiency, enhanced adaptability, facile seed production across diverse terrains, and substantial carbon sequestration capacity in the soil (Samson and Omielan, 1992; Sanderson et al., 1996).

The most important point of Switchgrass cultivation is the realization of a healthy plant. For this, the mechanization, soil preparation and sowing techniques to be applied are very important. With the experiences obtained from the results of previous projects in Türkiye, it was tried to create a system to utilize the existing agricultural tools and machinery in the most appropriate way for the cultivation and establishment of this plant (Soylu et al., 2010).

The research carried out within the scope of the TUBİTAK Project No. 114O941 titled "Adaptation of *Panicum virgatum* L. Plant, Creation of Adaptation Maps, Determination of Mechanization Characteristics, Energy Declaration and Biogas Production from Waste Bioethanol" was carried out in the Karapınar district of Konya province. The Kanlow variety of switchgrass demonstrated exceptional performance in terms of green biomass yield and dry grass yield. However, for the Haymana district of Ankara province, Cave in Rock, Shawnee and Shelter varieties were found promising for green biomass yield and the Kanlow variety was found promising for dry herbage yield. Alamo variety was recommended for green biomass yield at the Simav location (Soylu et al., 2010).

Switchgrass is a highly regarded plant for biofuel production worldwide, but unfortunately, it is not widely recognized in our country. If its cultivation is prioritized on a larger scale, significant gains in energy production could be achieved, positioning it as an important future energy source.

Sugar beet is an important agricultural crop with economic potential attributable to its high yield capacity. From literature sources, sugar beet yields range from 40 to 90 t ha $^{-1}$ and beyond (Ungai and Győri, 2007).

In a study conducted by Pospišil et al. (2006), the production of 42 sugar beet hybrids was investigated. The results revealed a wide range of yields, varying from 61 t ha^{-1} to an exceptional high of 101.54 t ha^{-1}.

Annual weather conditions significantly influence the yield and technological quality of sugar beet, as demonstrated by Pospišil et al. (1999) when identical sugar beet varieties were utilized throughout the years of research.

In terms of sugar beet by-effluents, in addition to sugar primary production, sugar beet by-products include dry or wet sugar beet noodles, molasses, saturation sludge and about 60% of the green mass of sugar beet leaves and heads. Previously used as cattle feed, the leaves and heads are now used as green manure on arable land. Given the global energy crisis, sugar beet is increasingly seen as a suitable energy crop for biofuel production (Szakál et al., 2007). Sugar beet production in Türkiye reached 18.9 million tons in 2023. Consequently, 756 thousand tons of sugar beet-derived agricultural waste was generated. The energy equivalent value of this agricultural waste is quantified as 265,881.2 TOE year^{-1} (Anonymous, 2023). In this context, it is anticipated that the utilization of agricultural wastes from sugar beet as a substrate in biogas production will yield significant energy gains.

In this study, it was aimed to determine the biogas potential produced as a result of different mixtures of cattle waste (CW), three different Switchgrass (*Panicum virgatum* L.) plants (SG1 (Kanlow), SG2 (Shawne), SG3 (Alamo)) and sugar beet leaves (BL).

2. Materials and Methods

2.1. Materials

2.1.1. Organic Materials Used in Biogas Production

The switchgrass varieties Kanlow, Shawnee, and Alamo were obtained from Konya Selçuk University, Faculty of Agriculture, Department of Field Crops. Switchgrass samples were ground and stored under optimal storage conditions (ideal humidity, temperature, etc.). Likewise, sugar beet leaf samples used in biogas production studies were obtained from different regions in Konya province. Sugar beet leaf samples were stored under optimal storage conditions (ideal humidity, temperature, etc.).

2.1.2. Establishment of Experimental Setup and Determination of Application Pattern to Determine Biogas Potential

To determine the biogas potential, the experimental setup (Figure 1) consisting of the glass jar, 10x7 polyurethane hose (Blue) (10m), 10 mm hose inlet ball valve (5 pieces), 10 pneumatic tees (5 pieces), 1/4 - 10 pneumatic rotary elbows (20 pieces) was installed.

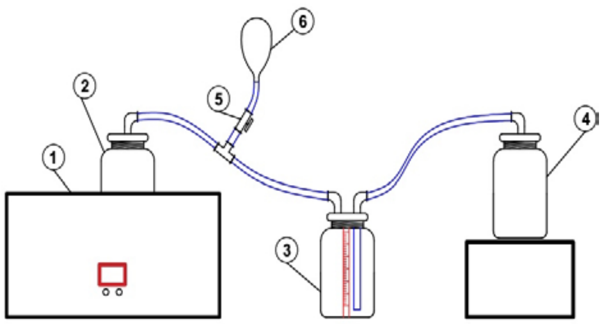

Figure 1. Experimental setup (1. Water bath device, 2. Reactor (Glass jar), 3. Acidified water (Gas outlet), 4. Water Inlet, 5. Gas sampling valve, 6. Gas storage balloon)

Within the scope of the research, an experimental design was created as the 1st experimental group, 2nd experimental group and 3rd experimental group. The experimental design is given in Figure 2.

First Group					Second Group				Third Group		
CW	SG-1 (Kanlow)	SG-2 (Shawne)	SG-3 (Alamo)	BL	CW-SG-1	CW-SG-2	CW-SG-3	CW-BL	CW(%50)- SG(%25) - BL(%25)	CW(%50)- SG(%30) - BL(%20)	CW(%50)- SG(%20) - BL(%30)

Figure 2. Experimental design

2.1.3. Instruments and Devices Used in Experiments

2.1.3.1. Water Bath Devices

JSR - JSIB-22T Series / Circulating Water Bath device and BW-10H Heating Bath (11.5L) device were used to maintain the reactor operating temperature as mesophilic (37±1) in the biogas setup. The BW-10H Heating Bath (11.5L) represents an economically viable solution for maintaining optimal temperature control in laboratory settings. This digital water bath exhibits remarkable temperature stability, making it a dependable choice for scientific and research experimentals

2.1.3.2. Precision Balance

Weighing of the samples and mixtures prepared to be used in the determination of biogas potentials was carried out with the help of "Denver Instrument" brand precision measuring balance with a maximum capacity and sensitivity of 0.1 mg and 210 g, respectively.

2.1.3.3. pH Measurement Paper

pH 0 - 14 pH-Indicator strip universal indicator Mcolorphast pH Paper was used to determine the pH values of the materials and mixtures in the experimental groups.

2.2. Metods

2.2.1. Performing Basic Characterization Analyses

A preliminary analysis were conducted to establish the dry matter and organic matter content for the energy crops switchgrass, sugar beet leaves, and cattle wastes. These were done to determine the appropriate quantities of these materials needed for the experimental setup, which is aimed at assessing biogas production and achieving the desired solids concentration in the reactor (refer to Table 1).

Table 1. Basic Characterization (Dry Matter, Organic Matter) Analysis

Sample Name	Organic Matter (%)	Sample (g)	Oven Dry (g)	Dry Matter (%)
SG-1 (Kanlow)	6.92	4.6506	4.3286	93.08
SG-2 (Aloma)	6.42	3.1603	2.9573	93.58
SG-3 (Shelter)	6.30	3.7667	3.5295	93.70
Sugar Beet Leaves	85.71	20.4167	2.9174	14.29
Cattle Waste	90.12	14.8338	1.4657	9.88

2.2.2. Determination of Dry Matter and Mixture Ratios

One of the desired reactor conditions to make the best use of bacteria groups fermenting in an oxygen-free environment to produce biogas and methane content is the dry matter level of the feed materials used (Von Mitzlaff, 1988). Biogas production is best when the total dry matter content of the feed materials is in the range of 6-13% (Šarapatka, 1993). Accordingly, the dry matter content was set to 10% in all treatments. Different mixing ratios were determined by optimizing with cattle waste, which was kept constant, and three different switchgrass varieties and beet leaf samples (Nagamani and Ramasamy, 1999).

2.2.3. Determination of the Amount of Biogas Produced

In the experiments, 1000 ml glass jar bottles served as reactors to assess the biogas quantity. The experimental setup was placed in a secluded area to shield it from sunlight. The reactors were maintained at mesophilic (37±°C) conditions. To maintain a constant temperature, JSR - JSIB-22T Series/recirculating water bath device and BW-10H heating bath (11.5 l) were used. To measure the biogas production, two glass jars were connected with pneumatic seals according to the water displacement principle. The first jar connected to the reactor was filled to the brim with water treated with sulfuric acid (H_2SO_4) (pH < 2) and sealed (Durgut, 2020). The volumes were determined by drawing on the glass jars from the Solidworks program on the PC, and the volumes corresponding to each mm length were determined and added to the glass jars for readings. The gas content of the space between the reactor and the glass jar filled with acidified water was measured by adding a valve to the connection line between the two containers. After the experiments, the gas collected via the valve was extracted from the gas containment flask and its content was analyzed. To ascertain the volume of biogas generated during the experiments, measurements were taken using scales placed under glass jars filled with water. In the conducted experimental setup, measurements of biogas production were monitored continuously for 30 days in experimental 1, 16 days in experimental 2, and 43 days in experimental 3 following the completion of biogas production from the materials. The collected biogas data was meticulously recorded and stored within a computerized system for analysis.

2.4. Statistical Analysis

This study was conducted according to the random plots trial design. Statistical analysis was performed using the JMP package version 5.0. Results were presented as means±standard errors (n=3) for the treatments. Differences between means were analyzed by one-way analysis of variance (ANOVA) followed by the LSD test, and the degree of difference was indicated by letters at the 5 % level. Heat map of Pearson's correlation coefficient matrix and principal component analysis of the evaluated attributes were produced by OriginPro 2019b (32Bit).

3. Results and Discussion

3.1. Biogas Values Produced from Materials

After completing the biogas production process in the experimental setup, measurements of biogas were taken continuously for 30 days in the 1st experimental, 16 days in the 2nd experimental, and 43 days in the 3rd experimental. These measurements were carefully recorded in the computer system. The biogas yield values obtained after 30 days in the 1st treatment group are presented in detail in Table 2 below.

Table 2. Total biogas yield values of the 1st experimental

Material	Biogas Yield Values (mL gDM^{-1})
CW	3504.07
SG1(KANLOW)	1971.4
SG2(SHAWNE)	1058.4
SG3(ALAMO)	822.5
BL	2148.8

When evaluating biogas yields, the highest yield of 3504.07 mL gDM^{-1} in CW was observed after 30 days. The other total biogas yield values obtained after 30 days from BL, SG1 (Kanlow), SG2 (Shawne), and SG3 (Alamo) materials were 2148.8 mL.gDM^{-1}, 1971.4 mL.gDM^{-1}, 1058.4 mL.gDM^{-1}, and 822.5 mL.gDM^{-1}, respectively. In the study conducted by Liew et al. (2012), the potential for methane production from various biomass feedstocks, including corn cobs, wheat straw, garden waste, and leaves, was examined through the process of anaerobic fermentation. Maximizing methane production was 81.2 L kg.VDM^{-1} from corn cobs, followed by wheat straw (66.9 L kg.VDM^{-1}), leaves (55.4 L kg.VDM^{-1}), and garden waste (40.8 L kg.VDM^{-1}). Within the scope of the experiments, the total biogas yield values determined from the 2nd and 3rd experimental group mixtures are shown in Table 3 below.

Table 3. Total biogas yield values determined from mixtures in the 2nd and 3rd experimental groups

Material	Biogas Yield Values (mL gDM^{-1})
CW-SG1	707.82
CW-SG2	119
CW-SG3	198
CW-BL	462.7
CW(%50)- SG(%25)-BL(%25)	151
CW(%50)- SG(%30)-BL(%20)	1913
CW(%50)- SG(%20)-BL(%30)	1997.5

In the second group, the highest biogas yield recorded was 707.82 mL. gDM^{-1} from the CW-SG1 mixture. Other biogas yields were 462.7 mL. gDM^{-1} from the CW-BL mixture, 119 mL. gDM^{-1} from the CW-SG2 mixture, and 198 mL. gDM^{-1} from the CW-SG3 mixture, respectively. Ahn et al. (2010) investigated the biogas production potential of switchgrass and a mixture of animal manure (cattle, poultry, and pig). They found the maximum methane yield to be 337 $mLCH_4.gVKM^{-1}$ in pig manure, 28 $mLCH_4.gVKM^{-1}$ in cattle manure, and 2 $mLCH_4.gVKM^{-1}$ in poultry manure. In the third experimental, the highest biogas yield observed was 1997.5 mL. gDM^{-1} from the CW(50%)-SG(20%)-BL(30%) mixture. Other biogas yields in the third cohort were 1913 mL. gDM^{-1} from the CW(50%)-SG(30%)-BL(20%) mixture and 119 mL. gDM^{-1} from the CW(50%)-SG(25%)-BL(25%) mixture, respectively. Lehtomäki et al. (2007) investigated the anaerobic treatment of energy crops, crop wastes, and manure mixtures in a semi-batch complete mixed reactor. They found that the highest methane yield from cow manure alone was 155 $mLCH_4.gVKM^{-1}$, while the highest methane yields achieved from anaerobic fermentation of cow manure with grass, sugar beet, and oat straw in certain proportions were 268, 229, and 213 $mLCH_4.gVKM^{-1}$, respectively.

3.2. Evaluation of Analysis

In light of the variance analysis, a statistically significant disparity was observed among the examined variables ($p < 0.01$) (Table 4). Subsequently, the LSD test was applied to these notable findings (Table 5).

Table 4. Results from Variance Analysis

Application	Average Biogas Yield (ml/gDM)	Standard Deviation	Standard Deviation Square (Variance)	Minimum (ml/gDM)	Maximum (ml/gDM)
CW-SG1	686.205	15.87	251.94	670.4	707.82
CW-BL	440.225	22.61	511.42	412	462.7
CW(50%)-SG(30%)-BL(20%)	135.4	16.27	264.72	112.4	151
CW(50%)-SG(20%)-BL(30%)	1731.667	198.92	39569.6	1455.2	1913
CW(50%)-SG(25%)-BL(25%)	1914.867	88.18	7775.68	1822.3	1997.5

Table 5. Results of LSD Test

Material	N	Standard Error Mean	Mean (1)
CW-SG1	4	8.093	686.205[b]
CW-BL	4	11.694	440.225[c]
CW(50%)- SG(25%)- BL(25%)	3	11.741	1914.867[a]
CW(50%)- SG(30%)- BL(20%)	3	140.455	135.4[d]
CW(50%)- SG(20%)- BL(30%)	3	50.819	1731.667[a]

(1)The means shown with different upper case letters in the same column are statistically significant (a-d: $p<0.01$, LSD=181.33).

When the table obtained according to the LSD results is examined, the highest biogas yield was obtained in the CW(50%)-SG(25%)-BL(25%) mixture, and the lowest biogas yield was obtained in the CW(50%)-SG(30%)-BL(20%) mixture.

4. Conclusion

This In this research, the biogas potential of the Switchgrass plant, previously analyzed for mechanization criteria in the TUBİTAK project was determined when it was combined with the high-yielding sugar beet plant, particularly abundant in Konya and its surrounding areas(Filikci, 2018). The resulting biogas yield was determined through its mixture with cattle waste. In the 1st experimental group, the highest biogas yield was determined as 3504.07 mL. gDM^{-1} in cattle waste (CW) at the end of the 30th day. The biogas yield values in the other materials in the 1st experimental group were determined as BL mL. gDM^{-1}, SG1(Kanlow) 1971.4 mL. gDM^{-1}, SG2(Shawne) 1058.4 mL. gDM^{-1} and SG3(Alamo) 822.5 mL. gDM^{-1}, respectively. In the 2nd experimental group, the highest biogas yield was determined as 707.82 mL. g DM^{-1} in the CW- SG1 mixture at the end of the 16th day. In the mixtures in the 2nd and 3rd experimental groups, the second was determined as 1997.5 mL.gDM^{-1} from the CW (50%)-SG (20%)-BL (30%) mixture. After reviewing the LSD test and variance analysis results, there is no significant statistical difference observed between the biogas yield values of the CW (50%)-SG (25%)-BL (25%) and CW (50%)-SG (30%)-BL (20%) mixtures. However, it was concluded that the biogas yield values of the CW (50%)-SG(25%)-BL(25%) and CW(50%)-SG(30%)-BL(20%) mixtures were the highest.

The use of BL mixtures resulted in high biogas yields and biomethane rates. When considering agricultural waste, beet leaves are a significant byproduct, especially in the sugar beet farming areas of Konya province and its surroundings. Although some beet leaves are used in animal feeding, complete disposal is not feasible. The substantial biomass from beet leaves can be converted into biogas energy through anaerobic fermentation, offering significant benefits. Agricultural mechanization and animal husbandry are key components of our economy. Currently, a large portion of energy needs in agricultural enterprises are met using non-renewable sources. Utilizing biogas, which is eco-friendly and reduces production inputs, is becoming increasingly important in meeting energy demands in agricultural enterprises. Biogas sources in agricultural enterprises include animal manure, various energy crops, and agricultural wastes. This not only enhances business efficiency but also mitigates environmental damage by reducing carbon dioxide (CO_2) emissions (Ayhan, 2013)

Author Contributions

The percentages of the authors' contributions are presented below. All authors reviewed and approved the final version of the manuscript.

	C.F.	T.M.
C	60	40
D	60	40
S	60	40
DCP	50	50
DAI	60	40
L	55	45
W	60	40
CR	55	45
SR	55	45
PM	50	50

C= concept, D= design, S= supervision, DCP= data collection and/or processing, DAI= data analysis and/or interpretation, L= literature search, W= writing, CR= critical review, SR= submission and revision, PM= project management, FA= funding acquisition.

Conflict of Interest

The authors declared that there is no conflict of interest.

Ethical Consideration

Ethics committee approval was not required for this study because there was no study on animals or humans.

Acknowledgments

This study was summarized from a part of the PhD Thesis titled *"Investigation of biogas yield of some vegetable and animal wastes and Switchgrass (Panicum virgatum L.)* mixtures*"*.

References

Ahn HK, Smith MC, Kondrad SL, White JW. 2010. Evaluation of biogas production potential by dry anaerobic digestion of switchgrass–animal manure mixtures. Appl Bioc Biot, 160: 965-975.

Anonymous 2023. Biogas formation stages, biogas usage areas. T.C. Enerji ve Tabii Kaynaklar Bakanlığı, https://enerji.gov.tr/eigm-yenilenebilir-enerji-kaynaklar-biyokutle (accessed date: December 14, 2025)

Ayhan A. 2013. A study on determining the amount of biogas that can be produced by mesophilic fermentation from cattle manure and corn silage at different mixing ratios. PhD thesis, Bursa Uludağ University, Institute of Science and Technology, Bursa, Türkiye, pp: 52.

Christian D, Elbersen H. 1998. Prospects of using Panicum virgatum (switchgrass) as a biomass energy crop. N. ElBassam (ed.), New York, USA pp: 257-263.

Durgut FT. 2020. Fabrication of a prototype biogas reactor for experimental purposes and evaluation of its performance in different biomass mixtures and media. PhD thesis, Tekirdag Namik Kemal University, Tekirdağ, Türkiye, pp: 47.

Eser V, Sarsu F, Altunkaya M. 2007. Current status and future of plants used in biofuel production. Biofs Biof Techn, 51: 61.

Filikci C. 2018. Determination of swıtch grass production mechanization features, MSc thesis, Selçuk University, Institute of Science and Technology, Konya, Türkiye, pp: 42.

Lehtomäki A, Huttunen S, Rintala J. 2007. Laboratory investigations on co-digestion of energy crops and crop residues with cow manure for methane production: effect of crop to manure ratio. Resour Conserv Recycl, 51(3): 591-609.

Liew LN, Shi J, Li Y. 2012. Methane production from solid-state anaerobic digestion of lignocellulosic biomass. Biomass Bioenergy, 46: 125-132.

Nagamani B, Ramasamy K. 1999. Biogas production technology: an Indian perspective. Current Sci, 44-55.

Pospišil M, Mustapić Z, Pospišil A, Tot I, Salaj M. 1999. Ispitivanje gospodarskih svojstava novih hibrida šećerne repe. Sjemenarstvo, 16(5): 403-413.

Pospišil M, Pospišil A, Mustapić Z, Butorac J, Tot I, Žeravica A. 2006. Proizvodne vrijednosti istraživanih hibrida šećerne repe. Poljoprivreda, 12(1): 16-21.

Samson RA, Omielan, JA. 1992. Switchgrass: A potential biomass energy crop for ethanol production. In: The Thirteenth North American Prairie Conference, 6-9 August, Windsor, Ontario, Canada, pp: 253-257.

Sanderson MA, Reed R, McLaughlin S, Wullschleger SD, Conger BV, Parrish D, Wolf D, Taliaferro C, Hopkins A, Ocumpaugh W. 1996. Switchgrass as a sustainable bioenergy crop. Bioresour Technol, 56(1): 83-93.

Šarapatka B. 1993. A study of biogas production during anaerobic fermentation of farmyard manure. Biomass Bioenergy, 5(5): 387-393.

Soylu S, Sade B, Öğüt H, Akınerdem F, Babaoğlu M, Ada R, Eryılmaz T, Öztürk O, Oğuz H. 2010. Investigation of agronomic potential of Switchgrass (Panicum virgatum L.) as an alternative biofuel and biomass crop for Turkey. European Biomass Conferance and Exihibition Proceedings, 9-12 June 2025, Valencia Italy, pp: 230-234.

Szakál P, Schmidt R, Lesny J, Kalocsai R, Barkóczi M. 2007. Quality parameters of wheat. Bio ethanol versus bread? Cereal Res Commun, 35: 1137-1140.

Ungai D, Győri Z. 2007. Possibility of increasing sugar yield by foliar treatments for crop production sustainability. Cereal Res Commun, 35, pp: 1241-1244.

Von Mitzlaff K. 1988. Engines for biogas. Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) GmbH (Braunschweig Vieweg is a subsidiary company of the Bertelsmann Publishing Group), Eschborn, Germany, pp: 1-132.

Black Sea Journal of Agriculture

doi: 10.47115/bsagriculture.1605635

Open Access Journal
e-ISSN: 2618 – 6578

Research Article
Volume 8 - Issue 2 : 158-164 / March 2025

THE EFFECTS OF NaCl SOLUTION APPLICATION FREQUENCY ON HAZELNUT SUCKER MANAGEMENT

Ümit SERDAR[1], Neriman BEYHAN[1], Coşkun GÜLSER[2], Burak AKYÜZ[1]*

[1]*Ondokuz Mayıs University, Faculty of Agriculture, Department of Horticulture, 55156, Samsun, Türkiye*
[2]*Ondokuz Mayıs University, Faculty of Agriculture, Department of Soil Science and Plant Nutrition, 55156, Samsun, Türkiye*

Abstract: Hazelnut is a nut species that is strategically important to Türkiye. Hazelnut cultivation has various cost factors, with the highest share belonging to the harvesting. Following harvesting, sucker management, and fertilization are the most significant cost factors. Due to high labor requirements and costs, sucker removal, which is recommended to be performed twice a year, is often conducted only once a year or every two years. This situation leads to reduced yield per hectare and income loss for producers. To reduce costs, some growers use herbicides to remove hazelnut suckers. However, the widespread use of herbicides causes irreversible environmental damage and can lead to erosion, particularly on sloped lands. Moreover, the continuous use of herbicides poses risks such as leaving residues in the soil, harming soil microorganisms, and threatening the health of hazelnut plants. This research aimed to determine the effects of the application frequency of a 15% salt (NaCl) solution on hazelnut sucker removal, focusing on its impact on soil EC and pH. The research was conducted at the Ondokuz Mayıs University Ali Nihat Gökyiğit Research Station from 2019 to 2021. NaCl solution applications were planned to be performed once, twice, and three times a year. The effects of application frequency on the drying rate of suckers, the number and length of newly emerged suckers, and changes in soil pH and EC were evaluated. The results revealed that applying the NaCl solution three times a year was the most effective method for sucker management and did not cause adverse changes in soil pH or EC levels.

Keywords: *Corylus avellana*, Sucker, Hazelnut, Salt

***Corresponding author:** Ondokuz Mayıs University, Faculty of Agriculture, Department of Horticulture, 55156, Samsun, Türkiye
E mail: burak.akyuz@omu.edu.tr (B. AKYÜZ)
Ümit SERDAR https://orcid.org/0000-0003-4703-6927
Neriman Beyhan https://orcid.org/0000-0002-1268-197X
Coşkun GÜLSER https://orcid.org/0000-0002-6332-4876
Burak AKYÜZ https://orcid.org/0000-0001-7356-776X

Received: December 23, 2024
Accepted: February 14, 2025
Published: March 15, 2025

Cite as: Serdar Ü, Beyhan N, Gülser C, Akyüz B. 2025. The effects of NaCl solution application frequency on hazelnut sucker management. BSJ Agri, 8(2): 158-164.

1. Introduction

The hazelnut (*Corylus*), native to Central Asia, the Caucasus, and Anatolia, belongs to the Betulaceae family within the Fagales order. According to FAOSTAT (2024), world hazelnut production in 2022 is 1195732 tonnes, and hazelnuts are produced in 32 countries. Türkiye, benefiting from its favorable ecological conditions and high-quality cultivars, ranks first among these countries, producing 765000 tons (FAOSTAT, 2024). This production accounts for approximately 64% of the world's hazelnut output.

In Türkiye, many hazelnut orchards are located in slopy areas. These slopes make mechanization challenging, increasing production costs and higher overall production expenses, thereby reducing profitability. One way to enhance profitability is by lowering production costs. The most significant cost factors in hazelnut cultivation are harvesting, sucker management, and fertilization (Okay et al., 1986; Karadeniz et al., 2009). The most grown hazelnut species, *Corylus avellana*, is known for its tendency to develop suckers. These suckers significantly reduce the orchard's ventilation and sunlight exposure, which harms productivity by competing with the main branches that provide fruit for nutrients and minerals. In modern, well-maintained hazelnut orchards, it is recommended to remove the suckers twice annually (Okay et al., 1986; Tous et al., 1994; Beyhan et al., 1995). However, due to high labor costs and intensive labor requirements, most growers perform sucker control only once a year or every two years (Kurnaz and Serdar, 1993).

Failing to remove hazelnut suckers as frequently as recommended negatively impacts the quality and yield of the hazelnut orchard. Figen et al. (2021) reported that removing hazelnut suckers twice a year increased yield by 27.7-55.9%, while cleaning them only once increased yield by 3.9-17.0%.

Sucker management in hazelnut orchards is predominantly carried out manually using pruning knives. Herbicides and other chemicals have been used instead of control by hand (Beyhan et al., 1996, Beyhan, 1997). However, the extensive and inappropriate use of herbicides harms the environment irreparably. Additionally, it leads to erosion, especially on sloped surfaces. Moreover, continuous use of herbicides poses risks such as residue accumulation in soil, harm to soil microorganisms, and potential threats to the health of hazelnut plants.

Some fertilizers have been tested as an alternative to herbicide use. In the research conducted by Serdar et al. (2022), the effects of different doses of ammonium sulfate (21% N) and calcium ammonium nitrate (26% N) on sucker wilting rates were evaluated. The results revealed that a 10% solution of ammonium sulfate was the most effective method on hazelnut suckers. In another research, sodium chloride (NaCl) solutions at different concentrations were tested as a more cost-effective alternative to fertilizer applications. The research found that a 15% NaCl solution had a positive result against suckers (Kondiloğlu, 2018). However, the frequency of the NaCl solution to be used has not been determined.

This research aims to determine the effects of application frequency of a previously proven 15% NaCl solution on hazelnut sucker control, as well as its impact on soil pH and EC.

2. Materials and Methods

This research was conducted on the 'Çakıldak' hazelnut cultivar in an orchard with a bush planting system from 2019-2021 (Serdar and Demir, 2005). The orchard is located at the OMÜ Ali Nihat Gökyiğit Research Station in the Kayagüney neighborhood of Atakum district, Samsun. In the first week of March 2019, all suckers were removed using a pruning knife. To prepare a 15% NaCl solution, 2.25 kg of rock salt was dissolved in 15 liters of water. The solution was then applied to the hazelnut suckers using a motorized sprayer. During the application, care was taken to thoroughly wet the suckers while avoiding any contact with the fruit-bearing branches. Approximately 1 liter of solution was sprayed onto each bush.

To evaluate the effects of NaCl solution application frequency on the control of hazelnut suckers as well as soil EC and pH, applications were conducted once, twice, and three times in 2019 and 2020 (Table 1 and 2). In 2020, due to ecological conditions, the application made in July was delayed by 15 days compared to 2019s.

Table 1. Application dates of the solutions made in 2019

Application Frequency	Application Dates		
	1st Application	2nd Application	3rd Application
Once a year	30 August	-	-
Twice a year	15 July	30 August	-
Three times a year	30 May	15 July	30 August

Table 2. Application dates of the solutions made in 2020

Application Frequency	Application Dates		
	1st Application	2nd Application	3rd Application
Once a year	30 August	-	-
Twice a year	30 July	30 August	-
Three times a year	31 May	30 July	30 August

All Bushes were fertilized with 1 kg 20:12:15+2 MgO+0.3B+0.5Zn in March and 0.5 kg calcium ammonium nitrate (CAN 26% N) in May.

To evaluate the effect of application frequency, measurements were taken at the end of the vegetation period for sucker length, wilting ratio of the suckers, number of newly emerged suckers, and length of newly emerged suckers. These measurements were conducted in the 30 x 30 cm area where the highest number of suckers was observed.

Soil samples were collected on 10.03.2019, 05.11.2019, 20.04.2020, 20.12.2020, and 02.06.2021 to determine the effect of NaCl solution application frequency on pH and EC changes in soil. Soil samples were taken from three different points within the canopy drip line of the bush at a depth of 0–20 cm, then mixed to create a composite soil sample for each replicate. Additionally, for control purposes, soil samples were collected from a 30 cm outside the canopy drip line of the bush (OCDL) to compare the effects of each treatment. Soil samples were brought to the laboratory, and pH and EC values were determined on the same day (Black, 1965).

2.1. Statistical Analysis

The research was conducted in 45 bushes with three treatment frequencies x 5 replications and three bushes in each replicate. A randomized plot experimental design was used for the research. Data analysis for each year was performed separately, using ANOVA in the SPSS statistical package. Differences between means were determined using Duncan's Multiple Comparison Test.

3. Results and Discussion

In 2019, the application frequency of once a year resulted in the longest sucker length (80.88 cm) with the lowest wilting ratio (6.73%) (Table 3). In contrast, applying the solution twice or three times a year significantly reduced sucker length (57.09 and 53.99 cm, respectively) while substantially increasing both the length of wilted suckers and wilting ratios (39.92 and 39.32 cm; 69.95% and 72.86%, respectively.

Table 3. The effects of salt solution application frequency on sucker length, length of the wilted part, and wilting ratio in 2019

Application Frequency	Sucker Length(cm)	Length of the Wilted Sucker (cm)	Wilting Ratio (%)
Once a year	80.88[a]*	5.47[b]	6.73[b]
Twice a year	57.09[b]	39.92[a]	69.95[a]
Three times a year	53.99[b]	39.32[a]	72.86[a]
P	≤0.01	≤0.01	≤0.01

* There is no difference between the means shown with the same letters in the column.

According to the newly emerged suckers, it was found that there were significant statistical differences between the application frequencies. The highest number of new shoots were obtained from 3 and 2 times a year application, with 12.00 and 10.66. (Table 4). Regarding the length of the newly emerged suckers, the longest suckers were obtained from the 1 and 2 times a year application (45.31 and 48.70 cm, respectively). In the 3 times a year application, the shortest newly emerged shoot length was measured (33.04 cm).

Table 4. The effects of different application frequencies of salt solution on the number and length of newly emerged suckers in 2019

Application Frequency	Number of the Newly Emerged Sucker	Length of the Newly Emerged Sucker (cm)
Once a year	6.66[b]*	45.31[a]
Twice a year	10.66[a]	48.70[a]
Three times a year	12.00[a]	33.04[b]
P	≤0.01	≤0.01

* There is no difference between the means shown with the same letters in the column.

A single application per year led to the most sucker growth (123.97 cm), with the shortest wilted sucker length (10.52 cm) and the lowest wilting ratio (8.68%) in 2020 (Table 5). Conversely, higher application frequencies (two and three times a year) reduced sucker length (70.72 and 49.94 cm, respectively) and increased both wilted sucker length (47.45 and 44.78 cm, respectively) and wilting ratios (68.03% and 89.66%, respectively). It was found that there was an inverse relationship between the frequency of application and the length of the suckers (Figure 1, 2).

Table 5. The effects of salt solution application frequency on sucker length, length of the wilted part, and wilting ratio in 2020

Application Frequency	Sucker Length(cm)	Length of the Wilted Sucker (cm)	Wilting Ratio (%)
Once a year	123.97[a]*	10.52[b]	8.68[c]
Twice a year	70.72[b]	47.45[a]	68.03[b]
Three times a year	49.94[c]	44.78[a]	89.66[a]
P	≤0.01	≤0.01	≤0.01

* There is no difference between the means shown with the same letters in the column.

Figure 1. Appearance of non-dried suckers after one application per year.

Figure 2. Appearance of dried suckers after three applications per year.

When the effects of NaCl solutions on the number and length of newly emerged shoots were analyzed, no statistical difference was found between the treatments (Table 6). While the number of suckers remained relatively low across all treatments (2.40, 1.00, and 1.10), their lengths showed a declining trend with increased frequency (67.68, 54.55, and 49.36 cm).

Table 6. The effects of different application frequencies of salt solution on the number and length of newly emerged suckers in 2020

Application Frequency	Number of the Newly Emerged Sucker	Length of the Newly Emerged Sucker (cm)
Once a year	2.40	67.68
Twice a year	1.00	54.55
Three times a year	1.10	49.36
P	N.S.	N.S.

N.S.= not significant

The research evaluated the effects of NaCl solution application frequency according to years. The results of all 2 years showed that the highest wilting ratio was obtained from the application 3 times a year. It is thought that this is due to the lack of sufficient lignification of the suckers in the 3 times a-year application. In addition, the lowest wilting ratios were obtained from the once-a-year treatment. Serdar et al. (2022) and Kondiloğlu (2018) also obtained similar results in their studies. In our research, it was determined that the most critical criterion affecting the wilting ratio was the lignification status along with the length of the suckers. In comparison, Serdar et al. (2022) noted that the optimal management of hazelnut suckers required at least three nitrogen solution applications annually to achieve effective sucker suppression without adverse impacts on plant health. However, they highlighted the importance of targeting suckers at specific growth stages (15-20 cm) to optimize wilting efficiency.

The hazelnut plant grows in shrub form and is generally cultivated using the bush system in Türkiye. In the bush system, plants should be replaced with the help of the suckers. In this respect, the applications should not negatively affect the number of newly emerged suckers. The frequency of applications showed varying effects on the number of new suckers. However, an increase in application frequency did not result in a significant decrease in the number of new suckers. On the contrary, in 2019, the highest number of new suckers was observed in areas where applications were performed three times a year. That shows 15% NaCl solution application did not have an adverse effect on newly emerged suckers

Soil samples were taken from the canopy drip line and outside the canopy drip line at five different times (March 10, 2019; November 5, 2019; April 20, 2020; December 20, 2020; and June 2, 2021). The changes in pH and EC values of these soil samples are presented in Table 7. Changes in soil pH and EC showed statistically significant differences (P<0.01) according to the sampling times. Still, these differences were generally insignificant between the treated and untreated (control) soil samples at the same sampling time.

Table 7. pH changes in the soils of the bushes treated with NaCl solution 1, 2, and 3 times a year (pH 1:1)

Sampling Dates	Application Frequency		
	Once a year	Twice a year	Three times a year
10.03.2019	7.11^{a*}	5.66^{a}	6.54^{a}
05.11.2019	7.32^{a}	5.66^{a}	6.66^{a}
05.11.2019 (OCDL)	7.11^{a}	5.66^{a}	6.54^{a}
20.04.2020	6.85^{b}	4.55^{de}	5.27^{c}
20.04.2020 (OCDL)	6.48^{cd}	4.80^{cd}	4.85^{d}
20.12.2020	5.45^{e}	4.30^{e}	4.71^{d}
20.12.2020 (OCDL)	5.24^{e}	4.93^{bc}	4.69^{d}
02.06.2021	6.31^{d}	5.11^{bc}	6.57^{a}
02.06.2021 (OCDL)	6.62^{c}	5.23^{b}	5.82^{b}
P	≤0.01	≤0.05	≤0.01

* There is no difference between the means shown with the same letters in the column. OCDL: Soil samples were taken 30 cm outside the canopy drip line of the bush

Table 8. EC changes in the soils of the bushes treated with NaCl solution 1, 2, and 3 times a year (EC, µS/cm)

Sampling Dates	Application Frequency		
	Once a year	Twice a year	Three times a year
10.03.2019	450.20[b]*	202.00[e]	305.20[cd]
05.11.2019	487.40[a]	265.00[d]	270.70[d]
05.11.2019 (OCDL)	450.20[b]	202.00[e]	395.20[b]
20.04.2020	202.85[f]	58.93[f]	92.92[f]
20.04.2020 (OCDL)	261.40[e]	55.51[f]	59.60[f]
20.12.2020	358.93[d]	385.30[b]	342.97[c]
20.12.2020 (OCDL)	189.60[f]	253.20[d]	183.30[e]
02.06.2021	404.00[c]	305.43[c]	513.00[a]
02.06.2021 (OCDL)	396.83[c]	506.53[a]	429.40[b]
P	≤0.05	≤0.01	≤0.01

* There is no difference between the means shown with the same letters in the column. OCDL: Soil samples were taken 30 cm outside the canopy drip line of the bush.

The change in soil pH showed a similar trend at sampling times in different frequencies of NaCl solution applications. The salt solution was prepared using NaCl, and since sodium (Na) can hydrolyze in the soil to form NaOH, a strongly alkaline compound, the application of the solution is expected to increase soil pH. However, in all solution treatments, soil pH decreased in the 3rd (20.04.2020) and 4th (20.12.2020) soil sampling dates and increased in the 5th (02.06.2021) sampling date. This increase was also observed in the soils taken from the outside of the canopy drip line of the bush. In addition, these increases and decreases show a similar trend in untreated soil samples in each sampling and do not show a statistically significant difference. This may be attributed to the addition of basic cations to the soil through fertilization applications or washing away from the soil during excessive rainy seasons rather than the application of NaCl solution. In 2019, rainfall was higher compared to 2020 (Table 9). This may have caused the nutrients supplied through fertilization (salts composed of cations and anions) to leach away from the soil. In contrast, the lower rainfall in 2020 may have led to the accumulation of these elements in the soil. This accumulation could have resulted in an increase in the EC value. A similar trend was also observed in the changes in EC values, which are indicators of the salt content of soils, as in soil pH. In all soil samples, the EC values being below 2000 µS/cm (2 dS/m) indicate that there is no risk of salinization in the soil. Soil samples taken from the application areas showed statistically significant increases and decreases in EC values. Similarly, soil samples collected from areas outside the canopy drip line exhibited a similar distribution. Overall, there is no significant difference in EC values between soil samples from areas with NaCl solution applications and others. In the last application of the 2 times a year NaCl solution, the EC value of the soil sample taken from the 30 cm outside the canopy drip line of the bush was found to be statistically significantly higher than the canopy drip line soil sample. This indicates that the EC changes in soil samples were not affected by the NaCl solution treatments. The variations are more likely attributed to seasonal sampling times, vegetative cover on the soil surface, or agricultural practices such as fertilization applied to the soil. Besides, the change in soil EC can be attributed to the addition of basic cations in the soil with fertilization practices or washing away from the soil during excessive rainy seasons rather than NaCl solution application.

In 2020, however, the lower rainfall may have led to the accumulation of these elements in the soil, resulting in an increase in EC values (Table 9).

Table 9. In 2019 and 2020, precipitation amounts by months (mm)

Months	Years	
	2019	2020
January	45.1	97.6
February	26.0	43.0
March	33.8	33.8
April	58.1	30.7
May	58.0	36.7
June	73.5	27.2
July	38.5	1.6
August	18.3	21.0
September	25.5	15.8
October	86.0	22.8
November	57.6	122.5
December	67.3	20.5

In the field, approximately 1 liter of a 15% NaCl solution is applied per bush in a single application, giving a total of 150 g of NaCl. With 3 applications, this amount reaches a total of 450 g. In a one-decare area (1,000 m^2), each tree has approximately 30 cm root depth, corresponding to a total of 300 m^3 of soil. Assuming the bulk density of the soil is 1.30 tons/m^3, the total soil weight is calculated as 390,000 kg. If there are 50 bushes in one decare, the soil weight per bush is 390,000 kg / 50 = 7,800 kg. In the case of 3 applications, a total of 0.45 kg of NaCl is added to 7,800 kg of soil, increasing the NaCl content in the soil by 0.0057%. According to Tüzüner (1990)'s soil salinity classification, reaching the lower limit of light salinity in the soil, which is 0.15%, would require repeating this application 26 times (equivalent to 26 years) without any rainfall (Table 10).

Table 10. Soil salinity classification (Tüzüner, 1990)

Total salt (%)	EC µS/cm	Degree of salinity
0.00-0.15	0-4000	Unsalted
0.15-0.35	4000-8000	Lightly salted
0.35-0.65	8000-15000	Moderately salty
More than 0.65	More than 15000	Excessive salty

Moreover, due to the structure of the NaCl, it dissolves very easily and washed away from the soil. In this case, it does not seem possible to increase soil EC or salinity in the long term by applying 1 L of 15% NaCl solution in the Black Sea region with high rainfall. The increase in soil salinity with the addition of plant nutrients in the soil applications made by farmers with fertilization can increase the EC in the soil even more than this application. Another negative effect of this application on the soil should have been an increase in soil pH due to Na, whereas soil pH generally decreased.

5. Conclusion

NaCl solution applications at different frequencies show statistically significant differences in pH and EC values between soil sampling times.

However, within the same sampling times, the changes in areas with and without NaCl applications are generally similar. This indicates that there is usually no statistically significant difference between these areas. Therefore, it can be concluded that NaCl solution applications do not cause significant changes in soil salinization or pH values. In this respect, it was observed that 3 times application frequency did not have a negative effect on the soil.

In conclusion, it has been determined that applying a NaCl solution once a year has a low impact on the wilting ratio. Therefore, it is recommended to implement sucker control three times a year in hazelnut orchards that have similar ecological condition as Atakum district

Author Contributions

The percentages of the authors' contributions are presented below. All authors reviewed and approved the final version of the manuscript.

	Ü.S.	N.B.	C.G.	B.A.
C	25	25	25	25
D	30	30	10	30
S	100			
DCP	30	10	30	30
DAI		30	30	40
L	25	25	25	25
W	20	20	20	40
CR	25	25	25	25
SR				100
PM	60			40
FA	25	25	25	25

C= concept, D= design, S= supervision, DCP= data collection and/or processing, DAI= data analysis and/or interpretation, L= literature search, W= writing, CR= critical review, SR= submission and revision, PM= project management, FA= funding acquisition.

Conflict of Interest

The authors declared that there is no conflict of interest.

Ethical Consideration

Ethics committee approval was not required for this study because there was no study on animals or humans.

Acknowledgments

The authors thank Ondokuz Mayıs University BAP Commission for supporting this research with project number PYO.ZRT.1901.18.019.

References

Beyhan N, Serdar Ü, Demir T. 1995. Karadeniz bölgesinde fındık, kestane ve ceviz yetistiriciliginin gelistirilmesi. In: Karadeniz Bölgesi Tarımının Geliştirilmesinde Yeni Teknikler Kongresi, 10-11 Ocak, Samsun, Türkiye, pp: 147.

Beyhan N, Serdar Ü, Demir T. 1996. 2,4-D ve Paraquat'ın fındık dip sürgünü kontrolünde kullanılabilme olanağı. In: Tarımsal Öğretimin 150. Yıldönümü Fındık ve Diğer Sert Kabuklu Meyveler Semp, 10-11 Ocak, Samsun, Türkiye, ss:154.

Beyhan N. 1997. Bazı herbisitlerin fındık dip sürgünü kontrolündeki etkileri. Anadolu J Agric Sci, 12(3): 45-55.

Black CA. 1965. Methods of soil analysis. Part I. American Society of Agronomy, Soil Sci Soci of America, New York, USA, No: 9, 1st ed., pp: 1-38.

FAOSTAT. 2024. Dünya fındık üretim miktarları. URL: http://www.faostat.org (accessed date: December 3, 2024).

Figen F, Serdar Ü, Akyüz B. 2021. Palaz fındık çeşidinde dip sürgünü temizleme sıklığının verim ve kalite üzerine etkisi. Akad Ziraat Derg, 10(2): 219-226.

Karadeniz T, Bostan SZ, Tuncer C, Tarakçioğlu C. 2009. Fındık yetiştiriciliği. Ordu: Zir Odalar İl Koord Kurul Yay, Ordu, Türkiye, No. 1, pp: 1-120.

Kondiloğlu C. 2018. Üre ve tuz çözeltilerinin fındık dip sürgünü kontrolünde kullanılabilirliği. MSc thesis, Ondokuz Mayıs Üniversitesi, Fen Bilimleri Enstitüsü, Samsun, Türkiye, pp: 27.

Kurnaz Ş, Serdar Ü. 1993. Fatsa ilçesi fındık işletmelerinin genel özellikleri, üretim tekniği ve yetiştiricilik sorunları üzerinde bir araştırma. Anadolu J Agric Sci, 8: 114-135.

Okay NA, Kaya A, Küçük VY, Küçük A. 1986. Fındık tarımı. T.C. Tarım Orman ve Köyişleri Bakanlığı, Teşkilatlanma ve Destekleme Genel Müdürlüğü, Yayın No: Genel 142, TEDGEM-12, Ankara, Türkiye, pp: 1-65.

Serdar U, Demir T. 2005. Yield, cluster drop and nut traits of some Turkish hazelnut cultivars. Hortic Sci., 32(3): 96-99.

Serdar Ü, Gülser C, Akyüz B, Balta A, Çil Y, Yilmaz Figen F. 2022. An alternative sucker management method in hazelnut: Application of nitrogen fertilizer solution. Erwerbs-Obstbau, 64(2): 237-244.

Tous J, Girona J, Tasias J. 1994. Cultural practices and costs in hazelnut production. In: III. International Congress on Hazelnut, September 14-18, Alba, Italy. Acta Horticulturae, 351: 395-418.

Tüzüner A. 1990. Toprak ve su analiz laboratuvarı el kitabı. TC Tarım Orman ve Köyişleri Bakanlığı, , Köy Hizmetleri Genel Müdürlüğü, Ankara, Türkiye, pp: 21-27.

Black Sea Journal of Agriculture

doi: 10.47115/bsagriculture.1621456

Open Access Journal
e-ISSN: 2618 – 6578

Research Article
Volume 8 - Issue 2 : 165-171 / March 2025

HISTOPATHOLOGICAL EXAMINATION OF THE LIVERS OF COMPULSORILY SLAUGHTERED HOLSTEIN DAIRY CATTLE

Kemal AKSOY[1]*, Korkut BOZKURT[2], Abdülkerim DENİZ[3], Mert METIN[4], Muhammed ÖZER[5]

[1]University of Muğla Sıtkı Koçman, Faculty of Veterinary Medicine Milas, Department of Internal Medicine, Muğla, Türkiye
[2]University of Health Sciences, İzmir Tepecik Training and Research Hospital, Department of Pathologhy, İzmir, Türkiye
[3]Independent Researcher in Biochemistry, Nispetiye District, Bakır Street, Beşiktaş, İstanbul, Türkiye
[4]University of Muğla Sıtkı Koçman, Faculty of Veterinary Medicine Milas, Department of Biochemistry, Muğla, Türkiye
[5]University of Muğla Sıtkı Koçman, Faculty of Veterinary Medicine Milas, Milas Veterinary Medicine Program, Muğla, Türkiye

Abstract: In recent years, many dairy cows in Türkiye have been compulsorily slaughtered before they have finished their lactation due to liver diseases. This study aimed to examine pre-slaughter clinical examination and post-slaughter liver tissue damage in Holstein breed dairy cows subjected to compulsory slaughter. In the present study, liver tissue from 85 Holsteins (n= 4 primiparous, n= 81 multiparous) aged 3-13 years that were delivered to slaughterhouses for compulsory slaughter was used. Clinical examination of all animals was performed before slaughter. After the obtained tissues were fixed, they were examined for steatosis, inflammation, fibrosis, and necrosis using histopathological methods. Lesions of varying degrees were found in 46% of the liver tissues analyzed. Among the reported findings were three examples of hepatic steatosis - one mild, one moderate and one severe. There were a total of 35 cases (41.2%) of liver inflammation that were found to be significant ($p<0.001$), of which 23 were mild, 6 moderate, and 6 severe. No fibrosis was detected in any of the samples, but only one sample showed mild necrosis. The clinical examination stated that rumen acidosis and dyspepsia led to slaughter in 35.3% of the animals, while 21.2% were sent to slaughter due to anestrus/uterus disease/infertility problems. In conclusion, histopathological findings indicated a significantly high liver inflammation and the majority of compulsorily slaughtered Holsteins had rumen acidosis/indigestion and anestrus/fertility problems.

Keywords: Fatty liver, Fibrosis, Compulsorily slaughtered, Inflammation, Necrosis

***Corresponding author:** University of Muğla Sıtkı Koçman, Faculty of Veterinary Medicine Milas, Department of Internal Medicine, Muğla, Türkiye
E mail: kemalaksoy@mu.edu.tr (K. AKSOY)
Kemal AKSOY https://orcid.org/0000-0003-0149-6688
Korkut BOZKURT https://orcid.org/0009-0009-7237-7775
Abdülkerim DENIZ https://orcid.org/0000-0002-5242-5671
Mert METIN https://orcid.org/0000-0002-1402-4594
Muhammed ÖZER https://orcid.org/0009-0004-5310-3430

Received: January 16, 2025
Accepted: February 21, 2025
Published: March 15, 2025

Cite as: Aksoy K, Bozkurt K, Deniz A, Metin M, Özer M. 2025. Histopathological examination of the livers of compulsorily slaughtered Holstein dairy cattle. BSJ Agri, 8(2): 165-171.

1. Introduction

The compulsory slaughter of a large number of breeding cows due to various diseases causes significant losses to the country's economy and farmers. 781947 high-performance dairy cows were compulsorily slaughtered between 2017 and 2019. Many of these slaughtered cows are due to metabolic diseases and infertility problems (Aksoy et al., 2021).

The liver is an important organ that plays the biggest role in metabolic processes in the body of a living organism. The main functions of the liver can be classified as metabolism, secretion, storage, synthesis, and detoxification. (Imren and Şahal, 2002). The liver is essential for giving periparturient dairy cows energy from various (Drackley et al., 2001).

It has been reported that in addition to bacterial, viral, and parasitic agents, many metabolic diseases also cause lesions in the liver (Stalker and Hayes, 2007; Metin, 2011). Hepatitis is the word for inflammation of the liver parenchyma, and it can be either acute or chronic (Dodurka, 2002; Cullen, 2007). The factors causing inflammation in the liver were viral and bacterial agents (Sağlam et al., 2003; Stalker and Hayes, 2007; Tadepelli et al., 2009; Metin, 2011; Buergelt et al., 2017), mycotic and parasitic diseases (*F. hepatica*, *Dicrocoelium dendriticum*), the toxic effects of certain drugs, immunological diseases, chronic diseases of the digestive system, inorganic, organic, and plant toxins, and toxins from diseases characterised by inflammation such as metritis and mastitis (Altun and Sağlam, 2014; Batmaz, 2016). Fibrosis, on the other hand, can develop as a result of chronic liver diseases, and the resulting damage can be irreversible (Friedman, 2000; Brown et al., 2010; Eulenberg and Lidbury, 2018). Hepatocytes may develop necrosis if the causes of liver tissue degeneration are not removed (Cheville, 1988; Milli and Hazıroğlu, 1997; Stalker and Hayes, 2007). Viral diseases cause not only inflammation in the liver but also degenerative and necrotic changes (Sağlam et al., 2003; Stalker and Hayes, 2007; Tadepelli et al., 2009; Metin, 2011).

Liver enzyme elevations are generally the first clinical-pathological changes observed in liver diseases. The damage occurring in the liver responds to a limited number of pathological changes. The occurrence of changes such as multiple necrosis and fibrosis in the final stage of this organ, along with the inflammatory response to dead cells, happens in the advanced stages of liver diseases. New hepatocytes or connective tissue cells (fibrosis) replace the dead cells (Buergelt at al., 2017).

Liver tissue damage is most commonly observed as fatty liver syndrome during the transition period in high-yielding dairy cows. Fatty liver, often known as hepatic lipidosis or fat cow syndrome, affects dairy cows mostly in the first few weeks of lactation but may already be evident just before or after parturition (Grummer, 1993; Bobe et al., 2004; Gross et al., 2013). During the first few months of lactation, between 50% and 60% of all dairy cows have higher hepatic lipid levels, according to a previous study by Jorritsma and colleagues (2000; 2001). Up to 40% of dairy cows with hepatic lipidosis in the first month after calving are estimated to have moderately fatty livers, and up to 10% have severe hepatic infiltration (Bobe et al., 2004). In the early postpartum phase, about 80% of downer cows had moderate to severe hepatic fat infiltration (Kalaitzakis et al., 2010). Additionally, the clinical relevance of hepatic lipidosis can be indirectly assessed by looking at the incidence rates of metabolic disorders that are closely connected, including ketosis (Gross, 2023).

In Türkiye, there has never been a study focussing only on compulsorily slaughtered Holsteins. Among the reasons for the compulsory slaughter of animals, it will be important to observe the occurrence of fatty liver, inflammation, necrosis, and fibrosis in the liver tissue. Without the invasive procedure in live animals, only slaughterhouse material was used in the present study for animal welfare reasons. The present study aimed to investigate pre-slaughter clinical findings and the histopathological changes in the liver tissue of compulsorily slaughtered Holsteins and the relationship between liver damage and the reason for slaughter.

2. Materials and Methods

2.1. Animal material

A total of 85 Holstein dairy cows brought to the slaughterhouse from 35 different villages with various diseases were examined clinically and histopathologically for liver tissue. After slaughter, liver samples were taken from dairy cows brought to the Menteşe and Milas slaughterhouses in the province of Muğla for compulsory slaughter.

The youngest cow was 3 years old, while the oldest was 13 years old, and the average age of the animals included in the study was 7 years. The lowest live weight of the animals sent for slaughter was 316 kg, while the highest live weight was recorded at 1090 kg. The average live weight of all the animals was 565 kg. Four Holsteins were primiparous, and 81 Holsteins were multiparous.

2.2. Clinical Examination

All animals underwent detailed antemortem clinical examinations before slaughter. Samples were taken from animals that were determined to have completed their productive lives and were suitable for slaughter. As a result of the clinical examination, liver samples were taken from 85 animals that were found to have completed their productive lifespan after slaughter.

2.3. Liver Material Collection

Immediately after the slaughter of dairy cows, four (4x10 g) liver tissue samples of 10 grams were excised from the caudal region of their livers and placed in ziplock bags (Gerspach et al., 2017). Earrings number, farm name, breed and age of the slaughtered animal were written on each sample bag. The samples were brought to the laboratory with +4 °C transport containers and the liver tissue was fixed with 10% formalin for histological examination.

2.4. Histopathological Examination of Liver Samples

Liver samples were divided into 8-micrometre thick sections using a frozen microtome and stained with Oil Red O. The same tissues were also routinely examined after being fixed with 10% formaldehyde, and 5-micrometre sections were cut from paraffin blocks. The sections were then stained with hematoxylin-eosin and prepared as two separate preparations for examination under the light microscope. Fat in liver cells histologically stained with red oil were classified as 1 (mild) if less than 33% of the cell (vacuole= 10 $\mu m^2/100\ \mu m^2$), 2 (moderate) if between 33-66% (vacuole= 10-20 $\mu m^2/100\ \mu m^2$), and 3 (severe) if greater than 66% (vacuole= 20 $\mu m^2/100\ \mu m^2$) **(**Brunt et al., 1999; Atasever et al., 2020**).** Inflammation, necrosis and fibrosis were graded between 0-3 (absent= 0, mild= 1, moderate= 2, severe= 3) (Sevinç and Aslan, 1998; Atasever et al., 2020).

2.5. Statistical Analysis

The software MedCalc (MedCalc Software Ltd, Belgium) version 2022 was used to perform the statistical analyses. Descriptive statistics were used to indicate the reasons for slaughter the frequency of liver damage percent, and the degree of damage as previously categorized. The chi-square test was used to determine whether the diseases detected in all samples were significant or not. A value of $p \leq 0.05$ is accepted as significant.

3. Results

3.1. Clinical examination

As a result of the clinical examination, diseases such as rumen acidosis, indigestion, and infertility were mostly detected. The clinical examination findings are detailed in Table 2. The clinical examination findings were found to be similar to the diseases mentioned in the official health report.

Table 1. Histopathological results of the 85 liver samples of Holsteins compulsorily slaughtered: number of adiposity, inflammation, necrosis and fibrosis in Primiparous (PRP, n= 4 total) and multiparous (MUL, n= 81 total) Holsteins

	Adiposty	Inflammation	Necrosis	Fibrosis
Positive (n, total)	3	35	1	0
Negative (n, total)	82	50	84	85
Positive % (total)	3.5	41.2	1.2	0
P	>0.05	<0.001	>0.05	NA
PRP positive (n)	0	2	0	0
PRP negative (n)	4	2	4	4
PRP positive (%)	0	50	0	0
P	NA	NA	NA	NA
MUL positive (n)	3	33	1	0
MUL negative (n)	78	48	80	81
MUL positive (%)	3.7	40.7	1.2	0
P	>0.05	<0.001	>0.05	NA

NA= not applicable.

3.2. Results of Histopathological Examination of Livers

The results of the histopathological examination of the 85 liver samples, the degree of adiposity, inflammation, necrosis and fibrosis were classified according to their severity and presented in Table 1 and Figure 1.

While 39 animals (45.9%) were found to have various degrees of different pathological findings, none of the four different pathological findings were found in the 46 liver samples (54.1%) that were assessed as healthy and without lesions. Various degrees of adiposity were found in 3 samples (3.5%). Inflammation was detected at a rate of 41.2% (n= 35). Out of 35 positive inflammation samples, mild inflammation was detected in 23, moderate inflammation in 6, and severe inflammation in 6. In 1 out of 85 samples, mild necrosis was detected, which corresponds to 1.2%. Fibrosis was not detected in any of the samples.

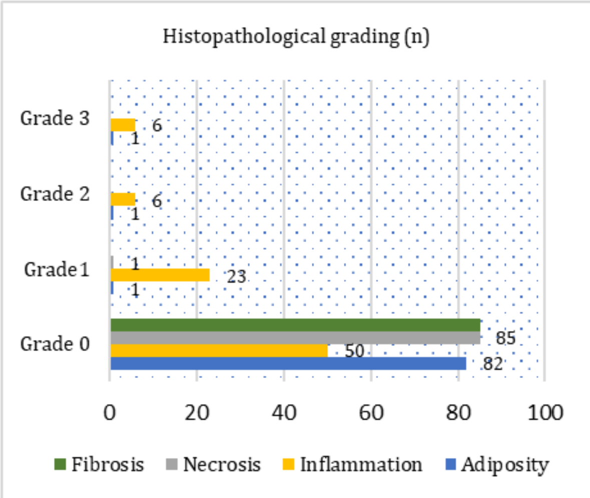

Figure 1. Results of the histopathological examination of the 85 liver samples from compulsorily slaughtered Holsteins: the degree of adiposity, inflammation, necrosis and fibrosis were classified according to their severity.

Table 2. Descriptive statistics on the causes of slaughter and liver inflammation by histopathological examination in 85 compulsorily slaughtered Holsteins

Reason for Compulsory Slaughter	Total compulsorily slaughtered (n= 85)		Liver inflammation (n= 35)	
	n	%	n	%
Chronic mastitis/mammary fibrosis	9	10.6	4	11.4
Omasum constipation	7	8.2	0	0.0
Reticuloperitonitis traumatica	6	7.1	4	11.4
Old age	4	4.7	2	5.7
Paralytic ileus	1	1.2	0	0.0
Indigestion and ruminal acidosis	30	35.3	13	37.1
Ovarian-dysfunction/anesturs/uterus diseases/infertility	18	21.2	8	22.9
Abomasum displacement	3	3.5	1	2.9
Abomasum ulcer	3	3.5	1	2.9
Milk fever	4	4.7	2	5.7

The reasons for the compulsorily slaughtered Holsteins with liver inflammation are shown in Table 2. Indigestion/rumen acidosis, ovarian dysfunction/infertility/uterine problems, RPT and chronic mastitis/mammary fibrosis were the reasons in the majority of Holsteins with liver inflammation. Most

Holsteins were sent to compulsory slaughter due to indigestion/rumen acidosis (35.3%) and ovarian dysfunction/anestrus/uterus problems (21.2%).

In the histopathological examination of tissue sections prepared from the livers (Figures 2, 3 and 4), the widespread distribution of macro and microvesicular fat vacuoles of varying sizes in hepatocytes within the liver parenchyma was noteworthy. Holsteins in this study had mild to severe inflammation, and the inflammatory infiltrates were distributed either periportally or diffusely throughout the liver tissue. Consequently, modest portal inflammatory infiltrates were present in the majority of hepatitis.

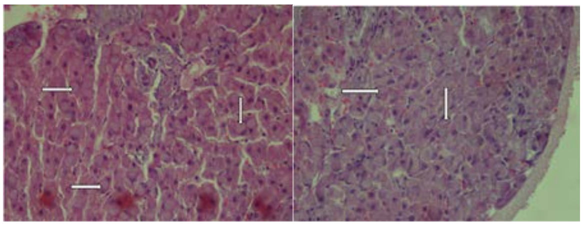

Figure 2. Grade 3 steatosis, stained with hematoxylineosin (white arrows).

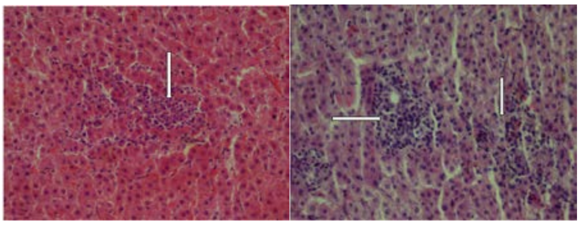

Figure 3. Lobular inflammation/Neutrophil and mononuclear cell infiltrations (white arrows).

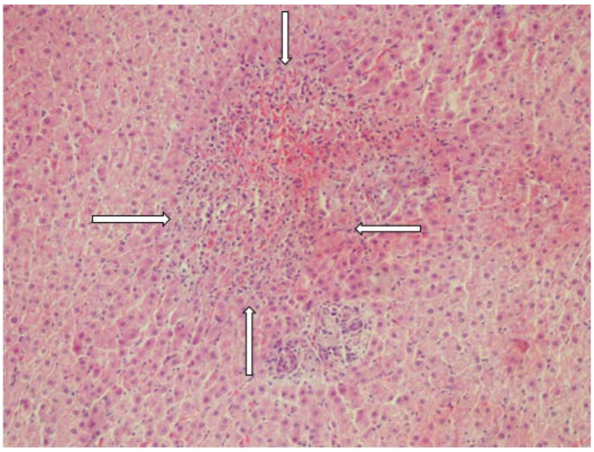

Figure 4. Mixed mononuclear / polymorphonuclear cell infiltration and accumulation in hepatic lobules and necrosis (white arrows).

4. Discussion

In Türkiye, most dairy cows go to slaughter before completing their lactation life. In fact, 781947 dairy cows were compulsorily slaughtered between 2017 and 2019 in Türkiye. Metabolic diseases played a major role in slaughtering dairy cows at an early age. Abomasal displacement, fatty liver disorders, milk fever, and ketosis were frequent, particularly in Holstein dairy cows (Aksoy et al., 2021). The present study aimed to examine histopathological changes in liver tissues of Holsteins slaughtered compulsorily in slaughterhouses. Instead of the hazardous and laborious method of taking a biopsy from the liver of a live animal, the liver tissues of freshly slaughtered dairy cows were examined.

Fatty liver is a common disease in dairy cows and is associated with many diseases (Wensing et al., 1997; Bobe et al., 2004). Additionally, there are correlations between fatty liver and a higher culling rate and a worse lifespan performance (Gross, 2023). Bacterial, viral, and parasitic agents, the toxic effects of some drugs, immune system diseases, and many diseases characterized by inflammation also cause inflammation in liver tissues (Stalker and Hayes, 2007; Tadepelli et al., 2009; Metin, 2011; Altun and Sağlam, 2014; Batmaz, 2016; Buergelt et al., 2017).

In a study conducted in Türkiye (Altun and Sağlam, 2014), 1381 bovine livers brought to the slaughterhouse were examined, and histopathological examination was performed on 100 liver tissues where lesions were detected during macroscopic examination. As a result of the examination, abscess formation was detected in 11% of the lesioned samples, connective tissue proliferation and cirrhosis in 21%, necrosis of varying sizes and locations in 38%, fat degeneration in 4%, hydropic degeneration and cloudy swelling in 56%, hyperemia and congestion in 17%, and pigmentation in 9%. The cattle breeds used in this study were unspecified and healthy animals were slaughtered, which differed from the present study. While fat degeneration was found to be 4%, which was close to our study, necrosis formation was found to be very high at 38% compared to the present study. In a study conducted in the Netherlands on the prevalence of liver steatosis in 218 live animals selected from 9 different farms, the prevalence of liver steatosis was found to be 54%. In this study, liver steatosis was investigated by measuring serum NEFA values and liver triacylglycerol levels in liver biopsies taken from the animals between 6-17 days postpartum (Jorritsma et al., 2001). A fatty liver can cause ketosis or subclinical ketosis in the postpartum period (Herdt, 1988; Gross, 2023). Subclinical ketosis leading to metabolic and reproductive diseases in high-producing cows has been observed in an average of 22-24% of dairy cows worldwide (Suthar et al., 2013; Brunner et al., 2019), while clinical ketosis has been observed in an average of 7.2% (Venjakob et al., 2017). Here too, fatty liver leads to a predisposition to postpartum disease due to reduced reproductive performance, lower milk yield and weakened immunity (Breukink and Wensing, 1997; Sevinç and Aslan, 1998; Geelen and Wensing, 2006; Gross, 2023.). In another study conducted in Türkiye in 1996, a relationship between fatty liver and hypocalcemia was found. In 20 dairy cows diagnosed with hypocalcemia, liver samples taken through biopsy procedures revealed varying degrees of fatty liver, approximately 70% (Sevinç and Aslan, 1998). In another study, 1400 bovine livers randomly selected from slaughtered animals were examined macroscopically, and a large number of parameters were investigated histopathologically in 100 of them that had lesions. Hyperaemia (17%), haemorrhage (4%), hydropic degeneration and fuzzy swelling (87%), lipidosis (13%), necrosis (26%), hepatitis (47%), kuppfer cell proliferation (56%), bile duct hyperplasia (13%), biliary fibrosis (17%), parenchymal fibrosis (3%), and melanosis (2%) were all found during the histopathological examination. Hyperaemia (1.21%), hemorrhage (0.29%), hydropic degeneration and fuzzy swelling (6.21%), lipidosis (0.93%), necrosis (1.86%), hepatitis (3.36%), kuppfer cell proliferation (4%), bile duct hyperplasia (0.93%), biliary fibrosis (1.21%), parenchymal fibrosis (0.21%), and melanosis (%0.14) were the rates, taking into account all of the cattle that were slaughtered (Oruç, 2009). The breeds of the animals included in this study, whether they are dairy cattle or beef cattle, were not reported, and they were stated to be healthy during the antemortem examination. In this study, the results obtained from the lesioned samples showed that the value for hepatitis was close to our study, while the values for fibrosis, necrosis, and lipidosis were numerically higher than those in our study. The fact that the animals used in the study were healthy upon antemortem examination, belonged to different breeds and were either beef or dairy cattle are important factors affecting the research results. In another study conducted in the province of Erzurum, Türkiye, the rate of steatosis was found to be 4%. In the same study, it was reported that necrotic areas were detected in 38% of the cases. In our study, necrotic areas were found in only 1 case. In this study, fibrosis was found in 21% of the cases with lesions, but in our study, no samples showed fibrosis. In this study, healthy male and female animals were used in the antemortem examination (Altun ve sağlam, 2014). Fibrosis mostly occurs as a result of chronic liver diseases and the damage it causes is irreversible. It can be said that there was no such serious liver damage in the animals included in our study. It can be speculated that the high level of inflammation observed in our study can suggest the presence of one or more of the factors such as viral, bacterial, mycotic, parasitic, and toxic agents that cause inflammation in the liver of compulsorily slaughtered cows in the present study.

There have been studies on the prevalence of parasitic diseases of the bovine liver (Celep et al., 1990; Gargılı et al., 1999; Şimşek et al., 2005; Balkaya and Şimşek, 2010) and pathological changes have been observed in the liver in Türkiye (Gözün ve Kıran, 1999; Durgut et al., 2003; Oruç, 2009; Balkaya et al., 2010; Altun and Sağlam, 2014). Celep et al. (1990) reported, the prevalence of species were as follows : Trematods; *D.dendriticum* (74.6%), *C.daubneyi* (39.4%), *F.hepatica* (25.3%), *P.cervi* (0.7%), Nematodes; *Ostertagia spp*. (65.5%), *Cooperia spp* (45.8%), *Oesophagostomum spp*. (32.4%), *T. axei* (31.0%), In another study, following the slaughter, the liver and lungs, as well as other internal organs, were inspected for hydatid cysts and for Fasciola species in the liver bile ducts. 717 (34.3%) of the 2088 animals tested positive for hydatic cysts. Of these cattle with the infection, 520 (72.5%) had hydatid cysts in their lungs, 83 (11.6%) had just liver cysts, and 109 (15.2%) had both liver and lung cysts (Balkaya and Şimşek, 2010). However, in these studies, there was no detailed information about dairy cattle or beef cattle. In our study, only liver samples from Holsteins brought to the slaughterhouse for compulsory slaughter were used.

Sending dairy cows to slaughter before completing their lactation period causes significant economic losses in animal husbandry (Aksoy et al., 2021). According to the Tigem 2024 report, one lactating Holstein dairy cow costs around €3803. Aksoy et al. (2021) reported that 260000 dairy cows are sent for forced slaughter every year. This represents an average annual economic loss of 989 million euros in Türkiye. Replacing forced slaughtered Holsteins in the dairy industry will take time and also incur additional costs.

5. Conclusion

In summary, the histopathological findings indicated a significantly high level of liver inflammation in compulsory slaughtered Holsteins and that rumen acidosis/indigestion and anestrus/fertility problems were the cause of slaughter in the majority of cows. This study has once again highlighted the urgent need to implement liver-protective protocols in herd management, particularly on family farms, to address this deficiency. It could be helpful for producers to establish a monitoring system in dairy farming.

Author Contributions

The percentages of the authors' contributions are presented below. All authors reviewed and approved the final version of the manuscript.

	K.A.	K.B.	A.D.	M.M.	M.Ö.
C	30	10	30	10	20
D	60		20		20
S			100		
DCP	10	40			50
DAI	50		50		100
L	20	20	20	20	20
W	70	10	20		
CR	20	20	20	20	20
SR	100				
PM	40	30			30
FA	50				50

C= concept, D= design, S= supervision, DCP= data collection and/or processing, DAI= data analysis and/or interpretation, L= literature search, W= writing, CR= critical review, SR= submission and revision, PM= project management, FA= funding acquisition.

Conflict of Interest

The authors declared that there is no conflict of interest.

Ethical Consideration

The present study was approved by the Animal Experiments Local Ethics Committee of Muğla Sıtkı Koçman University (approval date: Septeber 23, 2021, protpcele code: 33/21).

Acknowledgments

This research was supported financially by TÜBİTAK (2209-A University Students Research Projects Support Program, Application number 1919B012101249).

References

Aksoy K, Deniz A, Metin M. 2021. Retrospective study about the transformation of dairy cattle population in Turkey (1991-2019) and possible metabolic and reproductive problems. BSJ Health Sci, 4(2): 77-84.

Altun S, Sağlam YS. 2014. Pathological examinations of lesions seen in liver of the cows slaughtered in Erzurum province. Atatürk Üniv Vet Bil Derg, 9(1): 7-15.

Atasever A, Sayar E, Ekebaş G, Şentürk M, Eren M. 2020. The effects of pumpkin seed oil on chronic liver damage induced Carbon Tetrachloride in rats and determination of hepatic apoptosis and caspase activity. Dicle Üniv Vet Fak Derg, 13(1): 24-32.

Balkaya İ, Şimşek S. 2010. Erzurum'da kesilen sığırlarda hidatidosis ve fascioliasis'in yaygınlığı ve ekonomik önemi. Kafkas Üniv Vet Fak Derg, 16: 793-797.

Balkaya İ, Terim Kapakin KA, Atasever İ. 2010. Fasciola hepatica ile doğal enfekte sığır karaciğerlerinin morfolojik ve histopatolojik olarak incelenmesi. Atatürk Üniv Vet Bil Derg, 5: 07-11.

Batmaz H. 2016. Sığırların iç hastalıkları semptomdan tanıya tanıdan sağaltıma. Özsan Mat San, Bursa, Türkiye, 3rd ed., pp: 160.

Bobe G, Young JW, Beitz DC. 2004. Invited review: pathology, etiology, prevention, and treatment of fatty liver in dairy cows. J Dairy Sci, 87(10): 3105–24.

Breukink HJ, Wensing T. 1997. Pathophysiology of the liver in high yielding dairy cows and its consequences for health and production. Isr J Vet Med, 52: 66–72.

Brown DL, Winkle TV, Cecere T, Rushton S, Brachelente C, Cullen JM. 2010. Congenital hepatic fibrosis in 5 Dogs. Vet Pathol, 47: 102-107.

Brunner N, Groeger S, Raposo JC, Bruckmaier RM, and Gross JJ. 2019. Prevalence of subclinical ketosis and production diseases in dairy cows in Central and South America, Africa, Asia, Australia, New Zealand, and Eastern Europe. Transl Anim Sci, 3(1): 84–92.

Brunt EM, Janney CG, Di Bisceglie AM, Neuschwander-Tetri BA, Bacon BR. 1999. Nonalcoholic steatohepatitis: a proposal for grading and staging the histological lesions. Am J Gastroenterol, 94: 2467–2474.

Buergelt CD, Edward GC, Fabio DP. 2017. Bovine pathology, a text and color atlas. In: Buergelt CD, Clark EG, Del Piero F, editors. Bovine pathology, a text and color atlas: Hepatobiliary system and pancreatic diseases. CAB International (CABI), Oxfordshire, UK, 1st ed., pp: 161-169.

Celep A, Açıcı M, Çetindağ M, Coşkun SZ, Gürsoy S. 1990. Helminthological studies on cattle from the Samsun region. Etlik Vet Mikrobiol Derg, 6: 117-130.

Cheville NF. 1988. Veterinary pathology. Iowa State University Press, Ames-Iowa, USA, 3th ed., pp: 84-197.

Cullen J. 2007. Hepatotoxic agents: Liver, biliary system, and exocrine pancreas. In: McGavin M, Zachary J, editors. Pathologic basis of veterinary disease. Mosby Elsevier, Missouri, USA, 4th ed., pp: 393-461.

Dodurka T. 2002. Geviş getiren hayvanların iç hastalıkları. In: Gül Y, editor. Sindirim sistemi hastalıkları. Medipress Matbaacılık, Malatya, Türkiye, 1st ed., pp: 165-166.

Drackley JK, Overton TR, Douglas GN. 2001. Adaptations of glucose and long-chain fatty acid metabolim in liver of dairy cows during the periparturient period. J Dairy Sci, 84(E. Suppl.): E100-E112.

Durgut R, Ergün Y, Yaman M. 2003. Sığır akciğer, karaciğer ve üreme organ lezyonları üzerine bir mezbaha çalışması. Vet Cer Derg, 9: 27-30.

Eulenberg VM, Lidbury JA. 2018. Hepatic fibrosis in dogs. J Vet Intern Med, 32: 26-41.

Friedman S L. 2000. Molecular regulation of hepatic fibrosis, an integrated cellular response to tissue injury. J Biol Chem, 275(4): 2247-2250.

Gargılı A, Tüzer E, Gülanber A, Toparlak M, Efil İ, Keleş V, Ulutaş M. 1999. Trakya'da kesilen koyun ve sığırlarda karaciğer trematod enfeksiyonlarının yaygınlığı. Turkish J Vet Anim Sci, 23: 115-116.

Geelen MJ, Wensing T. 2006. Studies on hepatic lipidosis and coinciding health and fertility problems of high-producing dairy cows using the "Utrecht fatty liver model of dairy cows". A review. Vet Q, 28(3): 90–104.

Gerspach C, Imhasly S, Klingler R, Hilbe M, Hartnack S, Ruetten M. 2017. Variation in fat content between liver lobes and comparison with histopathological scores in dairy cows with fatty liver. BMC Vet Res, 13: 98.

Gözün H, Kıran MM. 1999. Konya mezbahalarında kesime alınan koyunların karaciğerinde patolojik incelemeler. Veterinarium, 10: 1-19.

Gross JJ, Schwarz FJ, Eder K, et al. 2013. Liver fat content and lipid metabolism in dairy cows during early lactation and during a mid-lactation feed restriction. J Dairy Sci, 96(8): 5008–5017.

Gross JJ. 2023. Hepatic lipidosis in ruminants. Vet Clin Food Anim, 39: 371–383.

Grummer RR. 1993. Etiology of lipid-related metabolic disorders in periparturient dairy cows. J Dairy Sci, 76(12): 3882–96.

Herdt TH. 1988. Fatty liver in dairy cows. Vet Clin North Am, Food Anim Pract, 4: 269-287.

Imren HY, Şahal M. 2002. Sığır hastalıkları. In: Alaçam E, Şahal M, editors. Sığır hastalıkları: Sindirim sistemi hastalıkları. Medisan Yayınevi, Ankara, Türkiye, 2nd ed., pp: 85-89.

Jorritsma R, Jorritsma H, Schukken YH, et al. 2000. Relationships between fatty liver and fertility and some periparturient diseases in commercial Dutch dairy herds. Theriogenology, 54(7): 1065–74.

Jorritsma R, Jorritsma H, Schukken YH, et al. 2001. Prevalence and indicators of postpartum fatty infiltration of the liver in nine commercial dairy herds in the Netherlands. Livest Prod Sci, 68: 53–60.

Kalaitzakis E, Panousis N, Roubies N, et al. 2010. Clinicopathological evaluation of downer dairy cows with fatty liver. Can Vet J, 51(6): 615–22.

Metin N. 2011. Veteriner patoloji. Tuna Matbaacılık, Aydın, Türkiye, 1st ed., pp: 82-112.

Milli ÜH, Hazıroğlu R. 1997. Veteriner patoloji. Tamer Matbaacılık, Ankara, Türkiye, 1st ed., pp: 143-204.

Oruç E. 2009. Mezbahada kesilen sığırlarda karaciğer lezyonları üzerine histopatolojik bir çalışma. Atatürk Üniv Vet Bil Derg, 4: 97-104.

Sağlam YS, Temur A, Aslan A. 2003. Detection of leptospiral antigens in kidney and liver of cattle. Dtsch Tierarztl Wochenschr, 110: 75-77.

Sevinç M, Aslan V. 1998. Sütçü ineklerde doğum felcinin karaciğer yağlanması ile ilgisi. Turk J Vet Anim Sci, 22: 23-28.

Stalker MJ, Hayes MA. 2007. Liver and biliary system, In "Jubb Kennedy and Palmer's pathology of domestic animals", In: Maxie MG, editor. Saunders/Elsevier, Philadelphia, USA, 5th ed., pp: 297-388.

Suthar VS, Canelas-raposo J, Deniz A, Heuwiese W. 2013. Prevalence of subclinical ketosis and relationships with postpartum diseases in European dairy cows. J Dairy Sci, 96(5): 2925-2938.

Şimşek S, Köroğlu E, Dumanlı N, Aktaş M, Şaki CE. 2005. Seroprevalence of cattle hydatidosis in some districts in the East Anatolian Region of Turkey. Turkish J Vet Anim Sci, 29: 1305-1310.

Tadepalli S, Narayanan SK, Stewart GC, Chengappa MM, Nagaraja TG. 2009. Fusobacterium necrophorum: A ruminal bacterium that invades liver to cause abscesses in cattle. Anaerobe, 15: 34-36.

Tigem, 2024. Damızlık büyükbaş (sığır) satış fiyatları. URL: https://www.tigem.gov.tr/Folder/GosterimDetayDosyasi/a22043a5-1f68-43c9-a35b-e943783442ea.pdf. (accessed date: January 15, 2025).

Venjakob PL, Borchardt S, Heuwieser W. 2017. Hypocalcemia-Cow-level prevalence and preventive strategies in German dairy herds. J Dairy Sci, 100(11): 9258-9266.

Wensing T, Kruip T, Geelen MJH, et al. 1997. Postpartum fatty liver in high-producing dairy cows in practice and in animal studies. The connection with health, production and reproduction problems. Comp Haematol Int, 7: 167-71.

Black Sea Journal of Agriculture
doi: 10.47115/bsagriculture.1624429

Open Access Journal
e-ISSN: 2618 – 6578

Research Article
Volume 8 - Issue 2 : 172-177 / March 2025

EFFECTS OF DIFFERENT TREATED WASTEWATER LEVELS ON MAIZE GERMINATED IN HYDROPONIC ENVIRONMENT

Murat KARAER[1]*

[1]Bilecik Seyh Edebali University, Faculty of Agriculture and Natural Science, Department of Biosystems Engineering, 11100, Bilecik, Türkiye

Abstract: This study aimed to evaluate the effects of different treated wastewater levels on maize germination in a hydroponic system. The experiment was conducted in the plant growth chamber of Bilecik Şeyh Edebali University laboratories using a randomized complete block design. Five irrigation treatments were applied, consisting of treated wastewater levels of 0%, 25%, 50%, 75%, and 100%. The results demonstrated that higher levels of treated wastewater (75% and 100%) negatively impacted parameters such as green forage yield, shoot length, and root length. Conversely, the best outcomes were observed at the 25% treated wastewater level, which significantly enhanced plant growth metrics. The highest green fodder yield as 13745.9 g m^{-2}, dry matter yield as 1559.54 g m^{-2} and plant height as 15.99 cm were obtained from TWW25 subject. These findings indicate that moderate levels of treated wastewater can be effectively utilized in hydroponic systems to optimize maize growth while minimizing potential adverse effects associated with higher wastewater concentrations.

Keywords: Treated waste water, Germination, Hydroponic system

***Corresponding author:** Bilecik Seyh Edebali University, Faculty of Agriculture and Natural Science, Department of Biosystems Engineering, 11100, Bilecik, Türkiye
E mail: murat.karaer@bilecik.edu.tr (M. KARAER)
Murat KARAER https://orcid.org/0000-0002-1920-181X

Received: January 21, 2025
Accepted: February 24, 2025
Published: March 15, 2025
Cite as: Karaer M. 2025. Effects of different treated wastewater levels on maize germinated in hydroponic environment. BSJ Agri, 8(2): 172-177.

1. Introduction

Water is a vital, limited, and strategically important natural resource essential for the survival of all living organisms on Earth (Mengü et al., 2008). In recent years, due to population growth, global warming, climate change, and other environmental factors, the water crisis has increasingly become a significant global issue. This growing crisis has led to a rise in research on the use of alternative water resources as access to clean water sources diminishes worldwide. In this context, one of the most critical alternative water resources is treated wastewater, which is reclaimed through advanced treatment technologies. The use of treated wastewater is particularly important in the agricultural sector, the largest consumer of water. The utilization of wastewater in agriculture offers a significant opportunity for both water resource conservation and sustainable agricultural practices. Especially in regions experiencing water scarcity, treated wastewater has become a viable alternative for agricultural irrigation. Owing to its content of organic matter and nutrients, treated wastewater can support plant growth, potentially reducing the need for chemical fertilizers (Pedrero et al., 2010). However, the use of wastewater in agriculture necessitates controlling its contaminants and pathogens. When appropriate treatment methods are employed, such water not only contributes to water savings but also enhances agricultural productivity (Angelakis et al., 2018). Therefore, the utilization of wastewater for agricultural irrigation is regarded as a critical strategy in addressing global challenges such as climate change and diminishing water resources.

In our country, the inability to ensure a sufficient supply of forage throughout the year in the livestock sector leads to suboptimal animal nutrition and threatens the sustainability of economically viable livestock activities. To meet the demand for forage, roughages obtained from pastures, meadows, and forage crop cultivation areas are utilized. Additionally, alternative sources such as cereal residues (straw, hay) and industrial crop by-products (pulp, etc.) are also employed. However, the provision of forage, especially during the winter months, emerges as a significant challenge. While dry hay and silage are commonly used in winter, a limited amount of forage pelleting is also carried out for animal feeding (Kılıç, 2016). Nevertheless, these sources fall short of fully meeting the forage requirements of livestock during the winter season. In this context, alternative solutions for forage provision are becoming increasingly important. The germination method conducted in hydroponic environments stands out as a potential solution to address forage needs.

Hydroponic systems are a prominent, sustainable, and efficient production technology within soilless farming methods. These systems eliminate the need for soil in agricultural production by using water-based solutions that deliver essential nutrients directly to plant roots. Hydroponic farming ensures the efficient use of water resources, reducing water consumption by up to 90% compared to traditional agriculture (Sharma et al., 2018). Furthermore, the faster access of plants to nutrients enhances growth rates and increases crop yields. Hydroponic systems also improve disease and pest control, thereby reducing the need for chemical pesticides (Resh, 2022). Consequently, hydroponic farming plays a critical role in ensuring food security, particularly in water-scarce regions and areas with high urbanization.

Hydroponic germination is of great importance as it enables the production of high-quality and sustainable feed for livestock. Through this method, water and nutrients are delivered directly to plant roots in a controlled environment, allowing for the rapid generation of dense biomass without the need for soil. Compared to traditional feed production methods, hydroponic systems require less water and land, making feed production more sustainable, especially in regions facing water scarcity and limited agricultural land (Naik et al., 2012). Additionally, hydroponic feed is highly digestible and rich in nutritional content, which can enhance the growth performance of livestock. This system contributes to the conservation of natural resources and reduces the environmental impact of livestock production (Sneath and McIntosh, 2003).

The use of treated wastewater in hydroponic germination holds significant potential for the efficient utilization of water resources. When treated wastewater meets the required hygiene and quality standards, it can be used for irrigation in hydroponic systems. Treated wastewater may contain organic matter and nutrients essential for plant growth, thereby reducing the need for fertilizers in hydroponic systems (Capra and Scicolone, 2007). However, potential risk factors such as salinity and heavy metal levels in the water must be carefully monitored and managed. With appropriate treatment techniques, these risks can be minimized, enabling the use of wastewater in hydroponic germination to conserve water and mitigate environmental impacts (Pedrero and Alarcón, 2009).

In this study, treated wastewater was diluted at different rates and used to germinate maize plants in a hydroponic system. The results indicated that treated wastewater applied at low concentrations promoted growth parameters.

2. Materials and Methods

The research was conducted in a climate-controlled chamber located at the laboratories of Bilecik Şeyh Edebali University. The plant material used in the study was the Pioneer P1551 silage maize variety. The seeds were germinated in plastic containers measuring 30×20 cm. The experiment was designed as a randomized complete block design with five different irrigation treatments and three replicates. The irrigation treatments were created by diluting treated wastewater at varying rates, as shown in Table 1.

Table 1. Experimental treatments and their descriptions

Irrigation Treatments	Description of Irrigation Treatments
TWW100	Germination with 100% Treated Wastewater
TWW75	Germination with 75% Treated Wastewater + 25% Fresh Water
TWW50	Germination with 50% Treated Wastewater + 50% Fresh Water
TWW25	Germination with 25% Treated Wastewater + 75% Fresh Water
Control	Germination with 100% Fresh Water

The treated wastewater used in the study was taken from Bilecik Şeyh Edebali University's wastewater treatment plant. The analysis results for the wastewater sample are given in Table 2.

Table 2. Analysis result of treated waste water

Parameters	Analysis Method	Analysis Result	Limit Value
pH	SM 4500H+B	7.28	6-9
Suspended Solid Matter	SM2540-D	53.350 mg/l	60
Chemical Oxygen Demand	SM5220 B	52.437 mg/l	160
Biochemical Oxygen Demand	SM 5210 D	21 mg/l	50

In all treatments, the seed density was adjusted to 4 kg m², and the germination process was carried out for 8 days. The room temperature was set at 24 ºC with a light cycle of 16 hours and a dark cycle of 8 hours. Before germination, the seeds were sterilized by soaking in a 10% sodium hypochlorite solution for 5 minutes. At the end of the 8 days, all materials in the containers were removed, and the necessary measurements and analyses were conducted. (Karaşahin 2014).

The properties determined in the study are as follows:

Green Forage Yield (g m²): The harvested green forage was weighed on a precision scale after being left outside for 1 hour. The amount obtained was then scaled to the area of the container, and the green forage yield per square meter was calculated (Karaşahin 2014).

Dry Matter Content (%): After weighing the green forage, 100 kg samples were taken and dried in a drying oven at 70 °C until a constant weight was achieved, after which they were weighed on a precision scale. The resulting values were expressed as a ratio to the green forage weight (Karaşahin 2014).

Dry Matter Yield (g m^2): This was obtained by multiplying the green forage yields by the dry matter content percentages (Karaşahin 2014).

Plant Height (cm): After harvest, five plants were randomly selected from each replicate and measured from the root region using a ruler (Daud et al., 2016).

Root Length (cm): After harvest, five plants were randomly selected from each replicate, and the root length was measured from the seed region using a ruler (Daud et al., 2016).

Fresh Weight of Root and Stem: The samples taken to determine root and stem lengths were weighed to determine their fresh weight (Atak et al., 2006).

Dry Weight of Root and Stem: The fresh weight samples were dried in a drying oven at 70 °C until they reached a constant weight, and then weighed to determine their dry weight (Atak et al., 2006).

The obtained data were subjected to analysis of variance (ANOVA) using the Minitab 19 software, and Tukey's multiple comparison test was used to compare the means.

3. Results and Discussion

To evaluate the usability of treated wastewater in hydroponic cultivation, a hydroponic germination trial was conducted using maize plants at different treated wastewater levels. At the end of the germination process, it was determined that the treated wastewater levels had statistically significant effects on the measured parameters.

The green fodder yield ranged from 13745.9 to 3713.5 g m^{-2}, with the highest green fodder yield observed in the TWW25 treatment and the lowest in the TWW75 treatment (Table 3). When the treated wastewater concentration exceeded 50%, significant decreases in yield were observed. This indicates that high TWW concentrations can negatively impact plant growth (Daifi et al., 2015). Specifically, the green fodder yields for the TWW75 and TWW100 treatments decreased to 3713.5 g m^{-2} and 4215.7 g m^{-2}, respectively. As the concentration of treated wastewater increased, a rise in dry matter content was observed. While the control group had a dry matter content of 11.5%, the TWW75 group reached the highest value at 14.9%. This increase suggests that plants under higher stress conditions may reduce water uptake (Tüfenkçi et al., 2023). The control and TWW25 groups exhibited the highest dry matter yields, at 1419.35 g m^{-2} and 1559.54 g m^{-2}, respectively. In contrast, significant decreases in dry matter yield were observed in the TWW50, TWW75, and TWW100 treatments, reflecting the restrictive effects of high TWW concentrations on plant growth. The results indicate that low concentrations of treated wastewater (TWW25) could serve as a suiTable irrigation source for maize plants, whereas higher concentrations adversely affect plant growth. Similar findings have been reported in studies on other plant species. It has been emphasized that treated wastewater at specific concentrations positively impacts germination and seedling development, thereby enhancing biomass and green fodder yields. However, excessive application of treated wastewater has been observed to negatively affect plant growth (Daud et al., 2016; Ramana et al., 2002; Yousaf et al., 2010; Rusan et al., 2007; Kardes et al., 2020).

These results are supported by the study of Pedrero et al. (2014), which suggested that the use of treated wastewater at low concentrations not only conserves water in agricultural production but also enhances yield.

Table 3. Effects of different treated wastewater levels on green fodder yield, dry matter content, and dry matter yield

	Green Fodder Yield ** (g m^{-2})	Dry Matter Content ** (%)	Dry Matter Yield** (g m^{-2})
Control	12329.4^{ab}	11.5^{c}	1419.35^{a}
TWW25	13745.9^{a}	11.3^{c}	1559.54^{a}
TWW50	5588.7^{bc}	12.7^{bc}	725.61^{b}
TWW75	3713.5^{c}	14.9^{a}	555.57^{b}
TWW100	4215.7^{c}	13.7^{ab}	581.1^{b}

*= P≤0.05; **= P≤0.01

Figure 1 and 2 illustrates the plant height values of maize germinated under different treated wastewater (TWW) levels. In the TWW25 treatment, plant height reached the highest value of 15.99 cm, indicating that low concentrations of treated wastewater promote plant growth. The plant height in the control group (10.84 cm) was statistically similar to the TWW50 (11.22 cm) and TWW100 (11.56 cm) treatments. However, the TWW75 treatment recorded the lowest plant height at 9.76 cm. This suggests that a moderate level of TWW may have an inhibitory effect on plant growth. The promotion of plant growth by low concentrations of TWW, due to increased nitrogen and other nutrients in the irrigation water, is supported by the literature (Smith et al., 2021). However, the toxic effects observed at higher concentrations, particularly due to salinity and the accumulation of heavy metals, can negatively impact plant metabolism (Brown and Wong 2018). The low plant height observed in TWW75 aligns with previous studies, which indicate that high ion accumulation or salinity induces osmotic stress, thereby limiting plant growth (Lopez et al., 2019).

Regarding root length, the control group exhibited the highest value of 9.84 cm. However, root length decreased under all treated wastewater applications. In the TWW25 group, root length was measured at 7.07 cm, which, while lower than the control, was statistically similar. In contrast, other TWW levels exhibited a significant reduction in root length. This decrease is likely attribuTable to the increased levels of salts, heavy metals, or other toxic compounds in the wastewater, which adversely affect root development. Similarly, studies by Rusan et al. (2007) and Yadav et al. (2002) have highlighted the negative effects of high levels of treated wastewater on plant growth parameters. These results indicate that treated wastewater should be applied at low concentrations when used for irrigation, as higher doses negatively impact plant growth. The findings suggest that low-level TWW applications optimize maize growth, whereas moderate and high levels increase the risk of toxicity.

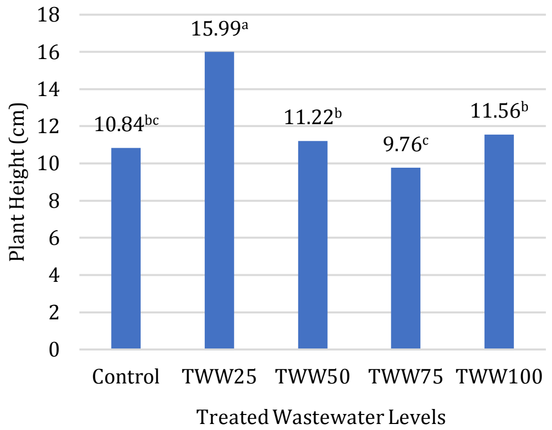

Figure 1. Effects of different treated wastewater levels on plant height.

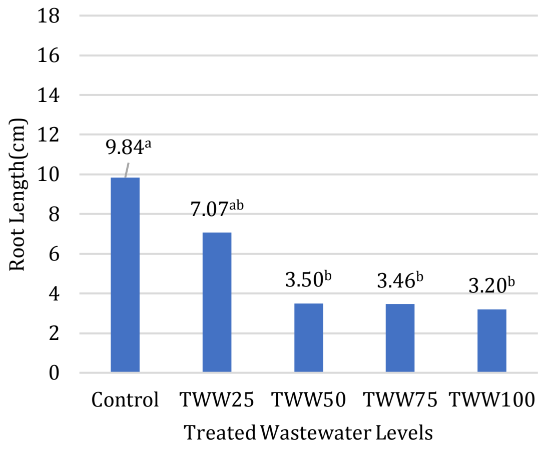

Figure 2. Effects of different treated wastewater levels on root length values.

When examining the effects of treated wastewater applications on the stem development of maize plants, it was determined that fresh weight values ranged between 2.04–1.30 g, while dry weight values varied between 0.14–0.23 g (Table 3). The highest stem fresh weight (2.04 g) was observed in the TWW25 treatment, indicating that low levels of treated wastewater could promote stem development. However, in the TWW75 (1.86 g) and TWW100 (1.76 g) treatments, fresh weight values were higher compared to the control group but lower than the TWW25 group, suggesting that increasing concentrations of treated wastewater might negatively affect stem growth.

In terms of dry weight, the TWW75 (0.22 g) and TWW100 (0.23 g) treatments achieved the highest stem dry weights compared to the control group (0.14 g) and the TWW25 treatment (0.21 g), indicating that medium and high levels of treated wastewater could enhance stem biomass density. Previous studies have reported that moderate levels of wastewater can stimulate plant growth through increased nutrient availability and nitrogen accumulation (Smith et al., 2021), while higher concentrations may exert toxic effects (Brown and Wong 2018). Additionally, the elevated dry weight values in the TWW100 group suggest structural density increases in stem cells (Lopez et al., 2019). Overall, the data indicate that low TWW levels (TWW25) provide optimal conditions for stem fresh weight, whereas the increase in stem dry weight at higher TWW levels (TWW75 and TWW100) may be associated with structural changes.

When the effects of treated wastewater applications on maize root development were examined, fresh weight values ranged between 0.67–0.39 g, while dry weight values varied between 0.13–0.06 g (Table 4). The TWW75 treatment provided an optimal environment, achieving the highest root fresh weight (0.67 g) and dry weight (0.13 g). This indicates that moderately diluted treated wastewater can enhance root biomass and density, thereby promoting root development. Although the control group exhibited a relatively high root fresh weight (0.58 g), it lagged behind the TWW75 group in terms of dry weight.

In the TWW100 treatment, significant reductions in both root fresh weight (0.39 g) and dry weight (0.06 g) were observed, suggesting that high concentrations of treated wastewater may hinder root development due to toxic effects such as salinity or heavy metal content. The literature highlights that moderate levels of wastewater increase nutrient availability and water retention in the root zone, whereas higher concentrations result in toxic effects (Brown and Wong 2018). High salinity levels, in particular, are known to induce water stress and adversely affect root growth (Lopez et al., 2019). These findings suggest that TWW75 could serve as an ideal irrigation strategy for root development in maize, although pretreatment technologies may be necessary to mitigate the toxic ions present at higher TWW levels.

Previous studies have also reported that low concentrations of treated wastewater positively impact plant growth, while increasing wastewater concentrations negatively affect plant development. Çatak and Korkmaz (2024) observed that the application of dye wastewater at concentrations of 25% or higher inhibited the growth of both tomato and pepper seeds, with adverse effects not only on seed germination but also on root and hypocotyl formation and development. Similarly, Gassama et al. (2015) found that low concentrations (<25%) of wastewater exhibited low phytotoxicity on crop growth and development, while higher concentrations (50%–100%) demonstrated significant phytotoxicity, reducing growth and development during the rice germination process

Table 4. Effects of different treated wastewater levels on fresh and dry weights of stems and roots

	Treated Wastewater Levels				
	Control	TWW25	TWW50	TWW75	TWW100
Fresh Weight of Root**(g)	0.58[ab]	0.46[ab]	0.49[ab]	0.67[a]	0.39[b]
Dry Weight of Root**(g)	0.07[b]	0.06[b]	0.07[b]	0.13[a]	0.06[b]
Fresh Weight of Stem**(g)	1.30[b]	2.04[a]	1.61[ab]	1.86[a]	1.76[ab]
Dry Weight of Stem**(g)	0.14[b]	0.21[ab]	0.20[ab]	0.22[a]	0.23[a]

*= P≤0.05; **= P≤0.01

4. Conclusion

This study was conducted to evaluate the effects of different levels of treated wastewater on maize seeds germinated in a hydroponic environment. The results revealed that the 25% treated wastewater level (TWW25) provided the most favorable conditions in terms of germination parameters. However, when the treated wastewater level exceeded 25%, significant reductions were observed in parameters such as germination rate, root development, and shoot growth. This indicates that high levels of treated wastewater have adverse effects on plant physiology. In conclusion, determining the optimal application levels is crucial for the safe and sustainable use of treated wastewater in agricultural practices.

Author Contributions

The percentages of the author' contributions are presented below. The author reviewed and approved the final version of the manuscript.

	M.K.
C	50
D	60
S	80
DCP	60
DAI	50
L	60
W	100
CR	50
SR	100
PM	100
FA	

C= concept, D= design, S= supervision, DCP= data collection and/or processing, DAI= data analysis and/or interpretation, L= literature search, W= writing, CR= critical review, SR= submission and revision, PM= project management, FA= funding acquisition.

Conflict of Interest

The author declared that there is no conflict of interest.

Ethical Consideration

Ethics committee approval was not required for this study because there was no study on animals or humans.

References

Angelakis AN, Asano T, Bahri A, Jimenez BE, Tchobanoglous G. 2018. Water reuse: from ancient to modern times and the future. Front. Environ. Sci, 6, 26.

Atak M, Kaya MD, Kaya G, Çikili Y, Çiftçi CY. 2006. Effects of NaCl on the germination, seedling growth, and water uptake of triticale. Turk. J. Agric. For., 30(1): 39-47.

Brown AK, Wong CS. 2018. Distribution and fate of pharmaceuticals and their metabolite conjugates in a municipal wastewater treatment plant. Water Res, 144: 774-783.

Capra A, Scicolone B. 2007. Recycling of poor-quality urban wastewater by drip irrigation systems. J Clean Prod, 15(16): 1529-1534.

Çatak E, Korkmaz F. 2024. Effects of dye wastewater on germination and plant development of some solanaceae family members. Süleyman Demirel Univ. J. Nat. Appl Sci 28(3): 483-489.

Daifi H, Alemad A, Khadmaoui A, El hadi M, El kharrim K, Belghyti D. 2015. Effect of purified industrial wastewater on the growth of tomato plant (Lycopersicon esculentum). Int. J. Pure App. Biosci. 3 (4), 57-64.

Daud MK, Hassan S, Azizullah A, Jamil M, Rehan N, Irum R, Qaiser MK, Zhu SJ. 2016. Physiological, biochemical, and genotoxic effects of wastewater on maize seedlings. Pol J Environ Stud, 25(2): 563-571.

Gassama UM, Puteh AB, Abd-Halim MR, Kargbo B. 2015. Influence of municipal wastewater on rice seed germination, seedling performance, nutrient uptake, and chlorophyll content. J Crop Sci Biotechnol, 18: 9-19.

Karaşahin M. 2014. Kaba yem kaynağı olarak hidroponik arpa çimi üretiminde kuru madde ve ham protein verimleri üzerine farklı uygulamaların etkileri. ISUBÜ ZFD 9 (1):27-33

Kardes YM, Karaer M, Köse ÖDE, Mut Z. 2020. The effect of treated wastewater applications on germination and seedling growth in three different corn (Zea Mays L.) Cultivar. BSEU J. Sci, 7(1): 113-120.

Kılıç Ü. 2016. Hydroponic Systems in Forage Production. TURJAF, 4(9), 793-799.

Lopez A, Rodríguez-Chueca J, Mosteo R, Gómez J, Rubio E, Goni P, Ormad MP. 2019. How does urban wastewater treatment affect the microbial quality of treated wastewater? Process Saf Environ Prot, 130: 22-30.

Mengü GP, Sensoy S, Akkuzu E. 2008. Effects of global climate change on agriculture and water resources. Balwois-Ohrid, May 27-31, Republic of Macedonia, pp. 143.

Naik PK, Dhuri RB, Swain BK, Singh NP. 2012. Nutrient changes with the growth of hydroponics fodder maize. Indian J Anim Nutr, 29(2): 161-163.

Pedrero F, Alarcón JJ. 2009. Effects of treated wastewater irrigation on lemon trees. Desalination, 246(1-3): 631-639.

Pedrero F, Kalavrouziotis I, Alarcón JJ, Koukoulakis P, Asano T. 2010. Use of treated municipal wastewater in irrigated agriculture: A review of some practices in Spain and Greece. Agric. Water Manag., 97: 1233-1241.

Pedrero F, Maestre-Valero JF, Mounzer O, Alarcón JJ, Nicolás E. 2014. Physiological and agronomic mandarin tree performance under saline reclaimed water combined with regulated deficit irrigation. Agric. Water Manag., 146: 228-237.

Ramana S, Biswas AK, Kundu S, Saha JK, Yadav RBR. 2002. Effect of distillery effluent on seed germination in some vegeTable crops. Biores Technol, 82: 273-275.

Resh HM. 2022. Hydroponic food production: a definitive guidebook for the advanced home gardener and the commercial hydroponic grower. CRC Press, New York, USA, 8th ed., pp. 512.

Rusan MJ, Hinnawi S, Rousan L. 2007. Long term effect of wastewater irrigation of forage crops on soil and plant quality parameters. Desalination, 215: 143-152.

Sharma N, Acharya S, Kumar K, Singh N, Chaurasia OP. 2018. Hydroponics as an advanced technique for vegeTable production: An overview. JSWC, 17(4), 364-371.

Smith JP, Boyd TJ, Cragan J, Ward MC. 2021. Dissolved rubidium to strontium ratio as a conservative tracer for wastewater effluent-sourced contaminant inputs near a major urban wastewater treatment plant. Water Res, 205: 117691.

Sneath R, McIntosh F. 2003. Review of hydroponic fodder production for beef cattle. Queensland Government, Department of Primary Industries, Dalby, Queensland.

Tüfenkçi Ş, Çakmakcı T, Yerli C, Şahin Ü. 2023. Arıtılmış atık suların bitki stres faktörlerine etkisi In: Yılmaz A, Yılmaz H, editors. Bitkilerde stress direncini artırma yöntemleri. İksad puplishing house, Ankara, pp. 201-220.

Yadav RK, Goyal B, Sharma RK, Dubey SK, Minhas PS. 2002. Post-irrigation impact of domestic sewage effluent on the composition of soils, crops, and groundwater: A case study. Environ Int., 28(6): 481-486.

Yousaf I, Ali SM, Yasmin A. 2010. Germination and early growth response of Glycine max varieties in textile and paper industry effluents. Pak J Bot, 42: 3857-3863.

Black Sea Journal of Agriculture
doi: 10.47115/bsagriculture.1623461

Open Access Journal
e-ISSN: 2618 – 6578

Research Article
Volume 8 - Issue 2 : 178-185 / March 2025

ANALYZING THE ROLE OF DEMOGRAPHIC VARIABLES IN RED MEAT PURCHASING DECISIONS: THE CASE OF IĞDIR PROVINCE

Osman Doğan BULUT[1]*

[1]*Iğdır University, Faculty of Agriculture, Department of Agricultural Economics, 76000, Iğdır, Türkiye*

Abstract: Red meat has an important place for a balanced and healthy diet. Researching red meat consumption is important to address many health, environmental and cultural issues. This study aims to determine the relationship between consumers' socio-economic characteristics, which are gender, income, education level, and criteria of red meat purchasing decision. The sample size was determined using the simple random sampling method. A survey based on face-to-face interviews was conducted with 384 consumers residing in the Iğdır province. The Mann-Whitney-U Test and Kruskal-Wallis Test were used in the statistical analysis of the study. It was determined that female consumers gave more importance to criteria such as food safety and whether the product was oily or not (P<0.05). Similarly, it was determined that price sensitivity decreased with the increase in income level, but health-related elements such as food safety became more prominent (P<0.01). It was observed that as the level of education increased, the importance given to whether the products were locally sourced also increased (P<0.05). These results can guide the determination of target market strategies for the red meat sector and the development of products and services to meet consumer expectations.

Keywords: Red meat, Purchasing decision criteria, Consumer preferences, Iğdır

***Corresponding author:** Iğdır University, Faculty of Agriculture, Department of Agricultural Economics, 76000, Iğdır, Türkiye
E mail: dgnblt@gmail.com (O.D. BULUT)
Osman Doğan BULUT https://orcid.org/0000-0003-2682-6356

Received: January 20, 2025
Accepted: February 24, 2025
Published: March 15, 2025

Cite as: Bulut OD. 2025. Analyzing the role of demographic variables in red meat purchasing decisions: The case of Iğdır province. BSJ Agri, 8(2): 178-185.

1. Introduction

Red meat has been an integral component of human diets for centuries, serving as a critical source of high-quality protein and essential micronutrients. (McAfee et al., 2010). Red meat provides bioavailable forms of key nutrients that are often difficult to obtain in sufficient quantities from plant-based sources. High- quality proteins from red meat contain all essential amino acids, making it a complete protein source. These attributes underscore the role of red meat as an important dietary component, especially in regions where malnutrition remains a public health concern. (Williams, 2007; Hurrell and Egli, 2010). Despite its nutritional value, red meat consumption has been the subject of ongoing debate due to health and environmental concerns. However, understanding its importance within a balanced diet and the socio-economic factors influencing consumer preferences is essential for public health and improving the service quality of retailers.

According to FAO data, world beef production in 2020 was 67.9 million tons, sheep/goat meat production was 16.1 million tons, and the USA (12.3 million tons) was in first place in beef production, while China (5.1 million tons) was in first place in sheep/goat meat production (FAO, 2020). According to TÜİK data, Türkiye's beef production in 2022 was 1.57 million tons, sheep meat production was 489 thousand tons, and goat meat production was 115 thousand tons (TÜİK, 2022). The per capita red meat production amount in Türkiye is 13.59 kg, which is well below the world average (Fidan, 2021).

Red meat purchasing is related to the issues discussed in the literature. These are quality attributes, price sensitivity, nutritional and health concerns, taste and culinary use, ethical and environmental considerations, cultural and regional influences, marketing and branding. This study focuses on consumers' purchasing decision criteria. Akbay and Boz (2005) state that consumers often prioritise freshness, as it is associated with better taste and safety. Visual cues, such as colour and texture, play a critical role in assessing freshness. Şengül (2016) made a strong case that price is a critical determinant, especially for low- and middle-income households. Consumers will always opt for cheaper cuts, alternative protein sources, or processed red meat products based on budget constraints. McAfee et al. (2010) found that awareness of red meat's nutritional benefits (e.g., high-quality protein, iron) drives purchasing decisions among health-conscious consumers. However, concerns about saturated fat, cholesterol, and links to chronic diseases (e.g., cardiovascular issues) remain. Gül (2010) showed higher-income households are more likely to afford premium cuts or grass-fed, organic meat, whereas low-income households prioritise affordability. Hurrell and

Egli (2010) have pointed out increasing awareness of food safety and ethical sourcing. Kadanali et al. (2010) found out that there is no relationship between income level of consumers and choice of place of meat purchase.

Although there are many studies on red meat consumption in the literature, there are limited studies on red meat purchasing preferences. It is thought that filling the gap in the literature will contribute. Consumers' red meat purchasing preferences is very important research topic because it provides leading information on healthy eating habits, contributes to the livestock industry, and helps retailers and policy makers understand the criteria consumers care about when purchasing products. This study aims to determine the relationship between consumers' socio-economic characteristics, which are gender, income, education level, and criteria of red meat purchasing decision. The aim of this study was to explore the socio-economic characteristics of consumers and the relationship between their purchasing decision criteria.

2. Materials and Methods

The main material of the research consists of original data obtained through a survey from 384 consumers living in Iğdır province in August-September 2024. In determining the number of households to which the survey was applied, the proportional sample size formula used to reach the maximum sample size in limited populations was used (Newbold, 1995). This method has been used in many studies on food consumption (Uzunöz et al., 2008; Karakaş, 2010; Akçay and Vatansever 2013; İkikat Tümer et al., 2017).

Formula (equation 1) used in sampling is:

$$n = \frac{N_p(1-p)}{(N-1)\sigma_{px}^2 + p(1-p)} \quad (1)$$

In the equation (1); "N" is the total number of people in the sample frame, "n" is the sample volume, "p" is the estimation rate (since the characteristics of the consumers constituting the main population are not known at the beginning, P=0.5 was taken to maximize the sample volume), "σ_{px}^2" is the variance of the rate (90% confidence interval and a 5% error margin were used to reach the maximum sample volume). In the formula, the population of Iğdır city center was taken as 132110 based on the TÜİK (2024) data as the main population, a 95% confidence interval and a 5% deviation from the mean were used, and the sample volume was calculated as 384.

The survey numbers were distributed to neighborhoods and villages in Iğdır province according to their household weights. These neighborhoods and villages were examined on the basis of geographical regions that could represent the city center. When determining these neighborhoods, attention was paid to reflecting all income and education groups. In determining the number of consumers to be interviewed in each settlement, the shares of the settlements in the total population were taken as basis and the consumers included in the sample were randomly determined.

In the research, consumers' red meat purchasing preferences were examined based on socioeconomic characteristics. The criteria considered important in the decision to purchase red meat were food safety, appearance, smell, freshness, price, packaging feature, whether fatty or not, whether imported or not, whether local animal or not. The research model is derived from some consumption studies in the literature, some of which belongs to Onianwa et al. (2006); Akpınar et al. (2009); Bulut et al. (2022). One of the most basic and popular scaling methods used in social science research is the Likert scale (Taherdoost, 2019). The degree of importance of the criteria in the decision to purchase red meat was measured using a 5-point Likert scale in which scales are strongly disagree (1), disagree (2), neither agree nor disagree (3), agree (4), strongly agree (5) (Preedy and Watson, 2010). The 5-point Likert scale analysis is commonly used because respondents can easily answer the questions in this format.

Kolmogorov Smirnov test was used to test whether the data showed normal distribution. The method used to test the normality assumption is normality tests. The fact that normality tests are significant indicates that the data differ significantly from the normal distribution. In contrast, the fact that normality tests are not significant indicates that the data do not differ significantly from the normal distribution (Demir, 2022). It was found that the criteria of "food safety, appearance, smell, freshness, price, packaging, fatty or not, whether imported or not and whether local or not" did not show a normal distribution according to the Kolmogorov-Simirnov normality test ($P<0.01$).

The Mann-Whitney test is a commonly used nonparametric alternative to the Two-sample T-Test (Perme and Menevski, 2019). The Kruskal-Wallis test is useful as a general nonparametric test for comparing more than two independent samples (Ostertagová et al., 2014). Since the assumptions of parametric statistics were not met, the Mann-Whitney U test and the Kruskal-Wallis test were preferred. The Mann-Whitney U test was used to assess the differences in the criteria for purchasing red meat by gender, divided into two groups, male and female. In addition, the Kruskal-Wallis test was used to assess the differences in red meat purchase decision criteria by household income level, divided into three categories, and education level, divided into four categories.

3. Results

3.1. Socio-economic Characteristics of Household Head

Socio-economic characteristics of household head are shown in table 1. Of the participants, 63.3% were male, 36.7% were female, the average age was 40.51, and 37.5% were 45 years of age or older. In terms of marital status, it was determined that the majority of the participants (77.9%) were married, and the highest group in terms of education level was secondary school graduates with a rate of 34.1%. While the highest rate among occupational groups was composed of freelancers (27.6%), it is noteworthy that the rate of unemployed individuals was 7.8%.

Table 1. Socio-economic characteristics of household head

Variables	Categories	Frequency	Percentage (%)
Gender	Male	243	63.3
	Female	141	36.7
Age (Year) (Mean: 40.51)	≤30	121	31.5
	31-44	119	31.0
	45≤	144	37.5
Marital status	Single	75	19.5
	Married	299	77.9
	Divorced	10	2.6
Education level	Uneducated	36	9.4
	Primary school	105	27.3
	Secondary school	131	34.1
	Higher education	112	29.2
Occupational group	Freelance	106	27.6
	Civil Servant	65	16.9
	Retired	18	4.7
	Farmer	61	15.9
	Private Sector Employee	50	13.0
	Tradesman	54	14.1
	Unemployed	30	7.8

3.2. Socio-economic characteristics of the household

Table 2 shows some Socio-economic characteristics of the household. The average household income was calculated as 38,747 TL and it was seen that 26.8.% of the participants were in the low-income group. The average household size was 3.96 people, and the most common household type was 3-4 people, with a rate of 45.1%. It was stated that only one person worked in 66.4% of the households, two people worked in 28.9%, and five or more people worked in 4.7%. These data reveal that the participants mostly came from medium-sized households and from economic groups that varied in terms of income level.

Table 2. Some characteristics of household

Variables	Categories	Frequency	Percentage (%)
Household income level (TL/month) (Mean: 38747.72)	Low (0-17002)	103	26.8
	Middle (17003-30000)	120	31.3
	High (30001≤)	161	41.9
Household size (person) (Mean:3.96)	≤2	67	17.4
	3-4	173	45.1
	5≤	144	37.5
Number of working individuals in the household	1	255	66.4
	2	111	28.9
	5≤	18	4.7

3.3. Importance Degree of Some Criteria for Purchasing Decision

Figure 1 illustrates the degrees of importance attributed by consumers to various criteria in their decisions to purchase red meat. The results emphasize that food safety, appearance, and smell are the most critical factors influencing purchasing behavior, followed closely by freshness and whether the product is locally sourced. These findings align with existing literature, which consistently underscores the centrality of food safety and product quality in consumer decision-making. For instance, McAfee et al. (2010) argue that consumers increasingly value food safety due to rising awareness of health risks associated with contaminated meat products.

Similarly, Şengül (2016) highlights that visual cues such as appearance and freshness significantly impact consumer perceptions of quality and safety, driving their purchasing preferences. Özüak (2021) states that the factors influencing the red meat preferences and purchasing behaviour of people living in Konya are the place of purchase (46.5%), the type of meat (17.7%), the way of purchase (13.0%), the fat content of the purchased meat (12.9%) and finally the price of meat. Yılmaz Tilki and Keskin (2024) state that almost all (98.9%) of the consumers who participated in the survey stated that they take quality into account when consuming and pointed out that various factors determine quality, especially the reliability of the place of purchase (17.8%), the colour of the meat (17.8%), the freshness (16.7%) and the smell (11.1%).

In contrast, price appears to hold relatively lower importance in consumer evaluations. This observation aligns with Gül (2010), who found that higher-income households tend to deprioritize price considerations in favor of quality attributes like freshness and safety. Moreover, as Wang et al. (2004) explain, the increasing awareness of health and environmental issues leads to a shift in consumer focus from cost-efficiency to quality and sustainability.

Overall, the findings from figure 1 indicate a clear consumer inclination towards health-conscious and quality-driven purchasing behavior. This aligns with broader trends identified in the literature, suggesting that consumer preferences are evolving towards a more nuanced evaluation of product attributes beyond mere cost considerations. Such insights provide valuable implications for stakeholders in the meat industry to develop marketing and production strategies that cater to these priorities.

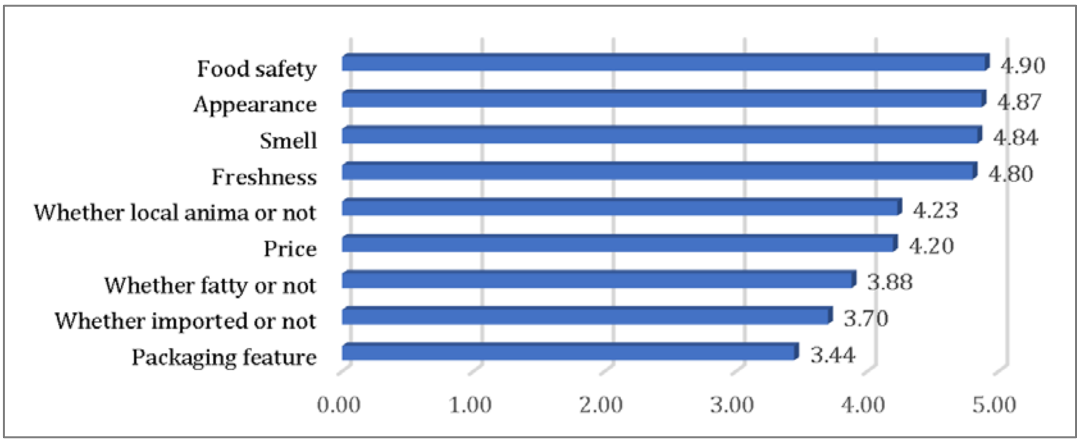

Figure 1. Importance degree of criteria in red meat purchasing decision.

3.4. Relationship Between Gender and Criteria in Red Meat Purchasing Decision

Table 3 presents the relationship between gender and various criteria influencing red meat purchasing decisions, analyzed using the Mann-Whitney U test. The results highlight significant gender-based differences in certain criteria. Women prioritize food safety ($P<0.05$) and fat content ($P<0.01$) more than men, reflecting a stronger focus on health-related factors. Conversely, men are more price-sensitive ($P<0.01$) and place greater importance on purchasing meat from local animals ($P<0.01$). No significant differences were observed between genders in evaluating criteria such as appearance, smell, freshness, packaging features, and whether the meat is imported, suggesting these factors are equally valued by both. These findings reveal that women tend to prioritize health and quality, while men focus more on cost and sourcing, providing valuable insights for tailoring marketing strategies.

3.5. Relationship Between Income Level and Criteria in Red Meat Purchasing Decision

Table 4 presents the relationship between household income level and the criteria that affect red meat purchasing decisions in detail. While households in the high-income group attach the highest importance to quality-related criteria such as food safety ($P<0.01$) and freshness ($P<0.01$), it is noteworthy that they are less sensitive to price ($P<0.01$). This situation shows that with the increase in income level, there is an increase in quality and health-oriented preferences in parallel with the decrease in the share allocated to food in total expenditures. On the other hand, households in the low-income group attach more importance to the price criterion and tend to prefer economical options. Those in the middle-income group exhibit a balance between these two extremes. Arısoy and Bayramoğlu (2015) posited that as income level increases, expense ratio for food decreases. Similarly, Sacli and Ozer (2017) determined that higher-income households allocate more resources to quality attributes such as freshness and safety. Gürbüz et al. (2023) stated that the change in income status affects the purchasing frequency of consumers.

The findings also show that consumers in the high-income group attach more importance to locally sourced products ($P<0.01$). It can be thought that the importance given to local production is due to the higher awareness of sustainability and product quality in consumers with high income levels. In addition, it is seen that the interest in imported products varies according to income level, and especially in the low-income group, imported products are not preferred (P<0.01). These trends reveal that the income level of consumers is a determining factor not only on price sensitivity but also on their perceptions of quality, health and local products. It can be said that table 4 provides an important guide in understanding consumer behavior in general and shaping marketing strategies according to income groups.

Table 3. Mann-Whitney U Test results for relationship between gender and criteria in red meat purchasing decision

Criteria	Gender	Frequency	Mean	Std. Deviation	Mann-Whitney U Test	P-value
Food safety	Female	141	4.950	0.218	15793.000	0.014**
	Male	243	4.864	0.378		
Appearance	Female	141	4.872	0.203	16450.500	0.136
	Male	243	4.864	0.275		
Smell	Female	141	4.844	0.364	17103.500	0.966
	Male	243	4.835	0.393		
Freshness	Female	141	4.801	0.466	16759.500	0.600
	Male	243	4.802	0.399		
Price	Female	141	3.922	1.208	13336.000	0.000
	Male	243	4.354	1.007		
Packaging feature	Female	141	3.418	1.116	16722.500	0.687
	Male	243	3.457	1.196		
Whether fatty or not	Female	141	4.121	0.815	13980.500	0.001*
	Male	243	3.741	1.092		
Whether imported or not	Female	141	3.631	1.085	16010.000	0.266
	Male	243	3.741	1.140		
Whether local anima or not	Female	141	3.972	1.388	14717.000	0.008*
	Male	243	4.379	1.062		

Significance level= *P-value < 0.01; ** P-value < 0.05

Table 4. Kruskal-Wallis Test results for income level and criteria in red meat purchasing decision

Criteria	Household income level	Frequency	Mean	Std. Deviation	Chi-Square	P-value
Food safety	Low	103	4.922	0.362	19.78628303	0.000*
	Middle	120	4.800	0.402		
	High	161	4.950	0.218		
Appearance	Low	103	4.864	0.269	0.243232919	0.885
	Middle	120	4.883	0.250		
	High	161	4.857	0.242		
Smell	Low	103	4.806	0.444	0.45327574	0.797
	Middle	120	4.850	0.359		
	High	161	4.851	0.357		
Freshness	Low	103	4.738	0.484	24.26048294	0.000*
	Middle	120	4.692	0.499		
	High	161	4.925	0.263		
Price	Low	103	4.621	0.818	62.26029171	0.000*
	Middle	120	4.533	0.819		
	High	161	3.671	1.229		
Packaging feature	Low	103	3.408	1.167	2.593560394	0.273
	Middle	120	3.317	1.202		
	High	161	3.559	1.134		
Whether fatty or not	Low	103	3.961	1.038	8.480813071	0.014**
	Middle	120	3.592	1.213		
	High	161	4.043	0.769		
Whether imported or not	Low	103	3.709	1.035	21.09260702	0.000*
	Middle	120	3.358	1.114		
	High	161	3.950	1.117		
Whether local anima or not	Low	103	4.214	1.234	15.81158157	0.000*
	Middle	120	3.942	1.318		
	High	161	4.453	1.054		

Significance level:*P-value < 0.01; ** P-value < 0.05

3.6. Relationship Between Education Level and Criteria in Red Meat Purchasing Decision

Consumers having higher education prioritize freshness and products, which are not imported, more (P<0.05). Similarly, As the level of education increases, the importance given to the freshness also increases (P<0.01). Also, price sensitivity decreases with education (P<0.01). The research findings are consistent with previous studies. Wang et al. (2004) and Islam et al. (2018) stated that with the increase in the level of education, the awareness level of consumers on food and health issues increases. Gül (2010) stated lower-educated consumers may prioritize factors such as taste, convenience, and affordability over nutritional or environmental considerations.

Table 5. Kruskal-Wallis Test results for education level and criteria in red meat purchasing decision

Criteria	Education Level	Frequency	Mean	Std. Deviation	Chi-Square	P-value
Food safety	Unschooled	36	4.839	0.3187	4.1739	0.243
	Primary school	105	4.848	0.4337		
	Secondary school	131	4.893	0.3101		
	University	112	4.946	0.2262		
Appearance	Unschooled	36	4.806	0.4014	10.35438	0.016**
	Primary school	105	4.867	0.2332		
	Secondary school	131	4.885	0.2404		
	University	112	4.886	0.2074		
Smell	Unschooled	36	4.694	0.5248	8.528602	0.036**
	Primary school	105	4.819	0.3868		
	Secondary school	131	4.832	0.3952		
	University	112	4.911	0.2864		
Freshness	Unschooled	36	4.639	0.5426	26.02782	0.000*
	Primary school	105	4.733	0.4857		
	Secondary school	131	4.763	0.4443		
	University	112	4.964	0.1864		
Price	Unschooled	36	4.500	0.7746	63.3479	0.000*
	Primary school	105	4.476	0.9913		
	Secondary school	131	4.443	1.0089		
	University	112	3.545	1.1381		
Packaging feature	Unschooled	36	3.417	1.2042	6.071958	0.108
	Primary school	105	3.210	1.2145		
	Secondary school	131	3.496	1.1189		
	University	112	3.607	1.1418		
Whether fatty or not	Unschooled	36	3.750	1.0522	2.654846	0.448
	Primary school	105	3.743	1.2406		
	Secondary school	131	3.870	0.9798		
	University	112	4.063	0.7627		
Whether imported or not	Unschooled	36	3.528	0.9996	67.58495	0.000*
	Primary school	105	3.448	1.1264		
	Secondary school	131	3.344	1.1352		
	University	112	4.411	.7659		
Whether local anima or not	Unschooled	36	3.889	1.2370	14.10129	0.003*
	Primary school	105	4.143	1.1883		
	Secondary school	131	4.145	1.3134		
	University	112	4.518	1.0309		

Significance level:*P-value < 0.01; ** P-value < 0.05

4. Conclusion and Recommendations

This study investigates the red meat purchasing preferences of consumers in Iğdır Province, focusing on the interplay between socio-economic factors—such as gender, income, and education level—and purchasing decision criteria. Utilizing a survey of 384 respondents and employing nonparametric statistical tests (Mann-Whitney U and Kruskal-Wallis), the research identifies significant variations in preferences based on demographic characteristics. The findings reveal that female consumers prioritize health-oriented factors such as food safety and fat content, while male consumers exhibit greater sensitivity to price and local sourcing. Higher-income households emphasize quality attributes like freshness and food safety, whereas lower-income groups display heightened price sensitivity. Furthermore, education level influences preferences, with more educated consumers placing greater importance on freshness and rejecting imported products. The results reinforce established consumer behavior theories that socio-economic factors such as gender, income, and education significantly influence purchasing decisions. Also, this study aligns with similar findings in Türkiye and internationally, suggesting trends in criteria for processing decision preferences.

This study contributes to the literature by underscoring the importance of tailoring marketing strategies to meet diverse consumer expectations. It was determined that the need for the red meat industry to adopt sustainable and consumer-focused approaches to address these differentiated preferences effectively. Results of the study can be used to define target market strategies for the red meat sector and to develop products and services that meet consumer expectations.

Author Contributions

The percentages of the authors' contributions are presented below. All authors reviewed and approved the final version of the manuscript.

	O.D.B.
C	100
D	100
S	100
DCP	100
DAI	100
L	100
W	100
CR	100
SR	100
PM	100
FA	100

C= concept, D= design, S= supervision, DCP= data collection and/or processing, DAI= data analysis and/or interpretation, L= literature search, W= writing, CR= critical review, SR= submission and revision, PM= project management, FA= funding acquisition.

Conflict of Interest

The author declared that there is no conflict of interest.

Ethical Consideration

The author confirm that the ethical policies of the journal, as noted on the journal's author guidelines page, have been adhered to. The experimental procedures were approved by Scientific Research and Publication Ethics Board Chairmanship of Iğdır University (Approval date and number: 14.08.2024/No: 23).

Acknowledgments

The author acknowledge the scientific support from Prof. Dr. Köksal KARADAŞ about the feasibility of the research topic and express their sincere gratitude for his help.

References

Akbay C, Boz I. 2005. Consumer preferences for red meat attributes in Tekirdağ province. Food Qual Prefer, 16(2): 125-132.

Akçay Y, Vatansever, Ö. 2013. Kırmızı et tüketimi üzerine bir araştırma: Kocaeli ili kentsel alan örneği. Çankırı Karatekin Univ Soc Sci Inst J, 4(1): 43-60.

Akpınar MG, Aykın SM, Sayın C, Ozkan B. 2009. The role of demographic variables in purchasing decisions on fresh fruit and vegetables. J Food Agric Environ, 7(3): 106-110.

Arısoy H, Bayramoğlu Z. 2015. Consumers' determination of red meat and meat products purchase behaviour – city of Ankara sample. Turk J Agric Food Sci Technol, 3(1): 28–34.

Bulut OD, Çelik Kaysim Z, Karadaş K. 2022. Determination of consumers' fresh fruit and vegetable (FFV) purchasing preferences during the Covid-19 pandemic period: the case of Türkiye. J Agric Fac Ege Univ, 59(4): 567-577.

Demir S. 2022. Comparison of normality tests in terms of sample sizes under different skewness and kurtosis coefficients. Int J Assess Tools Educ, 9(2): 397-409. https://doi.org/10.21449/ijate.1101295

FAO 2020. Food and agriculture organization. URL: http://www.fao.org/faostat/en/#data/QL (accessed date: October 3, 2024).

Fidan N. 2021. Kırmızı et bakımından gıda güvencesi. IJAAES, 3(4): 94-101.

Gül M. 2010. Socio-economic determinants of red meat consumption in Tokat province. J Agric Econ Res, 25(3): 45-55.

Gürbüz İB, Er S, Kadağan Ö. 2023. Bursa ilinde tüketicilerin kırmızı et tüketim tercihlerinin belirlenmesi üzerine bir araştırma. Bursa Uludag Üniv Zir Fak Derg, 37(2): 365-386. https://doi.org/10.20479/bursauludagziraat.1246716

Hurrell R, Egli I. 2010. Iron bioavailability and dietary reference values. Am J Clin Nutr, 91(5): 1461-1467.

İkikat Tümer E, Bulut OD, Şeker E. 2017. Tüketicilerin maraş tarhanası tüketim davranışlarının belirlenmesi; Kahramanmaraş ili örneği. Atatürk Univ. J Agric Fac, 48(2): 87-92.

Islam MJ, Sayeed MA, Akhtar S, Hossain MS, Liza AA. 2018. Consumers profile analysis towards chicken, beef, mutton, fish and egg consumption in Bangladesh. Br Food J, 120(12): 2818-2831.

Kadanali E, İkikat Tümer E, Dagdemir V, Miran, B. 2010. Analysis of factors affecting preferences of consumer's meat purchasing places. A case study Erzurum province. Turk IXth Agric Econ Congr, 22-24 September 2010, Şanlıurfa, Türkiye, pp: 320-325.

Karakaş G. 2010. Tokat ili kentsel alanda et ve et ürünleri tüketiminde tüketici kararlarını etkileyen faktörlerin belirlenmesi üzerine bir araştırma. Yüksek Lisans Tezi, Gaziosmanpaşa Üniversitesi, Fen Bilimleri Enstitüsü, Tokat, Türkiye, ss: 23

McAfee AJ, McSorley EM, Cuskelly GJ, Moss BW, Wallace JM, Bonham MP, Fearon AM. 2010. Red meat consumption: An overview of the risks and benefits. Meat Sci, 84(1): 1-13.

Newbold P. 1995. Statistics for business and economics. prentice-hall international, New Jersey, USA, pp: 72.

Onianwa O, Mojica M, Wheelock G. 2006. Consumer characteristics and views regarding farmers markets: An examination of on-site survey data of Alabama consumers. J Food Distrib Res, 37(1): 119–125.

Ostertagová E, Ostertag O, Kováč J. 2014. Methodology and application of the Kruskal-Wallis test. Appl Mech Mater, 611: 115–120.

Özüak A. 2021. Kırmızı et tüketim tercihlerinin konjoint analizi ile belirlenmesi. Yüksek Lisans tezi, Selcuk Üniversitesi, Fen Bilimleri Enstitüsü, Konya, Türkiye, ss: 25.

Perme MP, Menevski D. 2019. Nonparametric statistical tests in biomedical research. Stat Methods Med Res, 28(3): 711–722.

Preedy VR, Watson RR. 2010. 5-Point likert scale. In: Preedy VR, Watson RR, editors. Handbook of disease burdens and quality of life measures. Springer, New York, USA, 1st. ed., pp: 4288-4297.

Sacli Y, Ozer OO. 2017. Analysis of factors affecting red meat and chicken meat consumption in Türkiye using an ideal demand system model. Pak J Agric Sci, 54(4): 933-942.

Şengül S. 2016. Analysis of household food expenditures and red meat consumption in Ankara. J Consum Stud, 29(1): 87-101.

Taherdoost H. 2019. Importance of technology acceptance assessment for successful implementation and development of new technologies. Procedia Manuf, 33: 224–231.

TÜİK 2022. Türkiye İstatistik Kurumu. URL: https://data.tuik.gov.tr/Bulten/Index?P=Kirmizi-Et-Uretim-Istatistikleri-2022-49696. (accessed date: January 3, 2025).

TÜİK 2024. Türkiye İstatistik Kurumu. URL: https://data.tuik.gov.tr/Bulten/Index?P=Adrese-Dayali-Nufus-Kayit-Sistemi-Sonuclari-2023-49684 (accessed date: May 12, 2024).

Uzunöz M, Oruç Büyükbay E, Gülse Bal HS. 2008. Kırsal kadınların gıda güvenliği konusunda bilinç düzeyleri (Tokat ili örneği). Uludağ Univ J Agric Fac, 22(2): 35-46.

Wang JM, Zhou ZY, Yang J. 2004. How much animal product do the Chinese consume? Empirical evidence from household surveys. Aust Agribus Rev, 12: 1673-2016.

Williams P. 2007. Nutritional composition of red meat. Nutr Diet, 64: 113-119.

Yılmaz Tilki H, Keskin M. 2024. Gaziantep ili ölçeğinde kırmızı et tüketim tercihinin belirlenmesi. MKU Tar Bil Derg, 29(3): 873-884. https://doi.org/10.37908/mkutbd.1507134.

Black Sea Journal of Agriculture
doi: 10.47115/bsagriculture.1624100

Open Access Journal
e-ISSN: 2618 – 6578

Research Article
Volume 8 - Issue 2 : 186-193 / March 2025

ASSESSMENT OF WATER RESOURCES STATUS USING THE WATER FOOTPRINT CONCEPT: THE CASE OF TEKIRDAĞ PROVINCE

Hüseyin Tevfik GÜLTAŞ[1]*, Yeşim AHİ[2], Belgin ÇAKMAK[3]

[1]*Bilecik Şeyh Edebali University, Agricultural and Natural Sciences Faculty, Biosystems Engineering Department, 11230, Bilecik, Türkiye*
[2]*Ankara University, Water Management Institute, 06135, Ankara, Türkiye*
[3]*Ankara University, Agricultural Faculty, Farm Structure and Irrigation Department, 06135, Ankara, Türkiye*

Abstract: One of the fundamental steps in the protection and sustainability of water resources is monitoring and evaluation. By assessing the resources in terms of both quality and quantity, a clear depiction of the current situation can be established, which will form a solid inventory for the necessary actions. From the perspective of our country, the main issues concerning our water resources include the reduction in water quantity during periods of need due to excessive and uncontrolled use, the uncontrolled increase in pollution due to negligence linked to sectoral developments, and globally, the expected intense impact of climate change on the Mediterranean Basin, where we are located. The concept of the water footprint is one of the accepted methods for diagnosing the current state of water resources in terms of management planning and sustainability. The water footprint concept can effectively reveal how agricultural, industrial, and domestic uses impact water resources. In the present study, the agricultural water footprint of Tekirdağ, one of the most economically powerful provinces in the Thrace Region in terms of agriculture and industry, has been calculated and evaluated. Agriculture water footprint was found to be 1.33 billion cubic meters (BCM) in total, 0.61 BCM in crop production and 0.72 BCM in animal production. The green, blue and grey water footprint values for crop production were calculated as 0.11, 0.48 and 0.02 BCM, respectively. The results underscore the significant water demand of agricultural activities in Tekirdağ, highlighting the need for sustainable water management strategies to address resource utilization in crop and animal production.

Keywords: Water management, Agricultural water footprint, Water resources, Sustainability, Agriculture

***Corresponding author:** Bilecik Şeyh Edebali University, Agricultural and Natural Sciences Faculty, Biosystems Engineering Department, 11230, Bilecik, Türkiye
E mail: huseyin.gultas@bilecik.edu.tr (H.T. GÜLTAŞ)
Hüseyin Tevfik GÜLTAŞ https://orcid.org/0000-0002-4987-8522
Yeşim AHİ https://orcid.org/0000-0003-4426-4094
Belgin ÇAKMAK https://orcid.org/0000-0003-3557-8411
Received: January 21, 2025
Accepted: February 25, 2025
Published: March 15, 2025

Cite as: Gültaş HT, Ahi Y, Çakmak B. 2025. Assessment of water resources status using the water footprint concept: The case of Tekirdağ province. BSJ Agri, 8(2): 186-193.

1. Introduction

According to UN-Water's progress on implementation of integrated water resources management report at the current rate, the world will not achieve sustainable water management until at least 2049 – 25 years from now. It is predicted that in 2030, not too far from today, approximately 3.5 billion people in the world will not be able to cope with the effects of water scarcity due to economic inadequacies and severe effects such as climate change. Political commitments at the global level for sustainable water management have never been higher, but they have not been matched by the required finance or action on the ground in the report the evaluation of scientists (UN-Water, 2024). As is evident from the studies of institutions and organizations working on the subject, in the near future, regions including our country will face serious problems in accessing usable water resources in terms of quality and quantity.

Considering the Sustainable Development Goals (SDGs), it is seen that food, energy, ecosystem and climate change are among the goals related to water. For this reason, the status of water resources and monitoring and evaluation studies are very important. In the last 20 years, terrestrial water storage, including soil moisture, snow and ice, has declined at a rate of 1 cm per year, with significant implications for water security (WMO, 2021). According to the World Meteorological Organization Report for 2023, our country, and especially the Thrace Region, including Tekirdağ Province, has shown an extreme negative impact in the period between 2020-2023 in terms of reservoir storage and river flows (WMO, 2023). As is evident from the studies of institutions - organizations and scientists on the subject, in the near future, regions including Türkiye will face serious problems in accessing usable water resources in terms of quality and quantity (UN-Water, 2024, DSI, 2022). In order to prevent this situation and to ensure the sustainable use of existing water resources for agriculture, industry and domestic use, there are institutional and personal efforts to be made.

The decrease in the water resources of Tekirdağ province and the subsequent excessive pollution due to the ever-increasing industrial areas show visible effects today. With the developed industrial complexes in the province and the parallel development of agriculture, the subsurface water layers, which were 30-50 meters in the 1980s, have now reached a depth of several hundred meters and have suffered a significant loss in quantity. Therefore, allocations for groundwater use have been suspended by the State Hydraulic Works (DSI). Surface water resources are also experiencing quality deterioration and pollution, especially at very serious levels, under similar effects to groundwater resources. The amount of wastewater discharged into the Ergene Basin from Tekirdağ province is 200 million m^3/year (Anonymous, 2023a). Although it is clearly seen that this situation is not sustainable, although various plans and projects have been made, unfortunately, the implementation of the necessary measures in practice does not show a rapid development.

Considering agriculture, Tekirdağ province is one of the important agricultural production areas in Thrace. In the province, which has favourable conditions for cultivation in terms of soil characteristics and topography, 81% of the cultivated agricultural land consists of I., II. and III. class soils. For this reason, 30% of the country's sunflower production and a significant portion of wheat, canola and paddy production is provided from here. Due to the variations in the climate, the production amounts of other product groups, such as fruits and vegetables, are at very high levels (TSI, 2024).

Table 1. Changes in production area and quantity over the years in Tekirdağ Province

Years	2004		2022	
	Production area	Production quantity	Production area	Production quantity
Types	ha	tones	ha	tones
Orchards	9.184	73.283	11.662	82.936
Vegetables	8.112	174.400	2.960	95.698
Field Crops	366.775	1.380.096	405.710	1.767.989

Table 1 shows the changes in the cultivation areas and production amounts of the crop groups in the last twenty years. Tekirdağ province's significant agricultural cultivation capabilities have encouraged the development of agriculture-based industry in parallel. The strength of agricultural production as well as industry makes the situation more complicated in this region where water resources are very limited and polluted.

The study will assess agricultural water use in Tekirdağ province from a different perspective and discuss the current situation. The water footprint approach will analyse water resource consumption at the province level and provide guidance for future projections. It will highlight practical successes and identify necessary actions if there are gaps, thus providing valuable insights to scientists and decision makers. In light of this information, it will help to better manage water resources and ensure the sustainability of food supply.

2. Materials and Methods

2.1. Materials

The study was conducted using data on agricultural production and water resources of Tekirdağ Province. Tekirdağ is located at 40° 59' north latitude and 27° 29' east longitude on the northern coast of the Marmara Sea. The province is only 4 m above sea level. The Mediterranean climate is generally dominant on the coasts of the Marmara Sea. However, unlike the coastline of the Mediterranean Region, snowfall can be seen in the coastal area in winter. In the interior of the province, continental climate is dominant with hot summers and cold winters. According to long-term meteorological data (1991-2020), the average annual temperature is 14.5 °C, the average sunshine duration is 5.7 hours and the average annual precipitation is 601.1 mm (TSMS, 2022). The changes in temperature, precipitation and daytime sunshine duration values, which can have a significant impact on plant water consumption and the use of water resources, are given in figure 1.

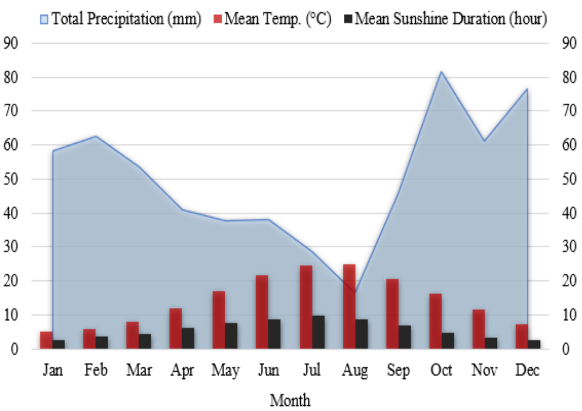

Figure 1. Change of meteorological parameters based on long-term averages.

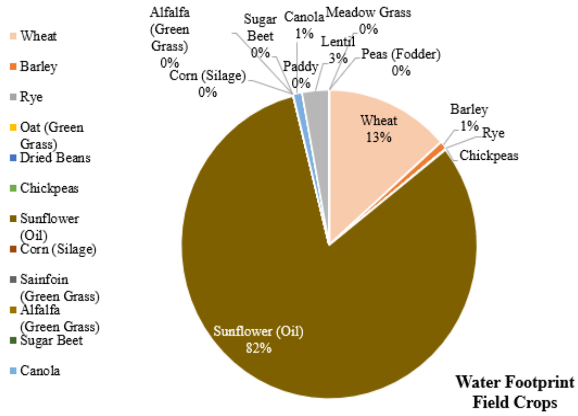

Figure 2. Water footprint of field crops

Tekirdağ province has a total water resource of 1.27 billion m³, including approximately 1.1 billion m³ of surface water and 263 million m³ of groundwater. When surface water resources are evaluated, the Ergene River 26.49 $m^3 s^{-1}$ and Hayrabolu stream 4.4 $m^3 s^{-1}$ stand out among the rivers, which are trying to cope with a serious pollution load. Karaidemir Dam, Ferhadanlı Dam and Türkmenli Dam are important as large reservoirs and Hanoğlu, İnanlı and Yazır Ponds are important for large-scale irrigation and drinking water supply. Underground water resources are realized as 19 million m³ irrigation water in 9 sections and 115 million m³ for industrial use (DSI, 2022).

National data used for the analysis were obtained from multiple data sources, while global data on water footprint indicators were obtained from the tables described by Mekonnen and Hoekstra (2011, 2012). Groundwater and surface water resource potential, water use, number of livestock and meteorological data for Tekirdağ province in 2022 were obtained from Turkish Statistical Institute, Ministry of Agriculture and Forestry General Directorate of State Hydraulic Works, General Directorate of Agricultural Research and Policies, Ministry of Environment, Urbanization and Climate Change General Directorate of Meteorology and Food and Agriculture Organization (DSI, 2022; TSMS, 2022; Anonymous, 2023b).

2.2. Methods

The study focused on calculating the volume-based blue, green, and grey water footprints described by Hoekstra et al. (2011). The blue water footprint (WFblue) indicates the portion of consumed groundwater or surface water. The agricultural water footprint has been determined by calculating the total green, blue, and grey water requirements of crops grown in the region. The Green Water Footprint (WFgreen) is considered as the total volume of rainwater used in the production of a product, while the grey water footprint (WFgrey) is calculated as the total volume of water needed to neutralize pollutants (Hoekstra et al., 2011; Ercin and~~ve~~ Hoekstra, 2012).

The method developed by Chapagain and Hoekstra (2004) for determining the water footprint of crop production has been used. In crop production, the water footprint largely depends on the water consumption of the plants. Plant water consumption consists of two main components: rainfall and irrigation water. In the research area, water footprint values in m³/year and m³/ton have been calculated using the water footprint method developed by Chapagain et al. (2006). The necessary meteorological data for the calculations were obtained from the General Directorate of Meteorology (TSMS, 2022). To determine the water footprint of crop production, plant water consumption and effective rainfall were first calculated using the TAGEM-SUET (tagemsuet.tarimorman.gov.tr) application, resulting in the green and blue water needs. The Penman-Monteith method was used for plant water consumption and the USDA-SCS method for effective rainfall in the application. Plant water consumption (ET, m³/ha) is calculated as the sum of the blue and green water needs (Chapagain and Hoekstra, 2004).

Table 2. Annual water footprint of animal category and some selected food products

Water footprint of animal type				Water footprint of animal products				
Animal category	Number of animal head	WF_{mean} (m³/animal)	WF_{total} (10^6 m³)	Product	WF_{green} (m³)	WF_{blue} (m³)	WF_{grey} (m³)	WF_{total} (10^6 m³)
Cattle	146914	1889	277.52	Milk	196764000	19608000	16416000	232.8
Buffalo	1715	20558	35.26	Eggs	176256	16592	29172	0.2
Sheep	307050	141	3.31	Chicken meat	2176630	192182	286738	2.7
Goat	40887	76	43.29	Beef	90231640	3443000	2823260	96.5
Broiler	95178	6	0.57	Sheep	13683474	757706	87874	14.5
Egg poultry	272078	47	12.79	Goat	150240	14880	12576	0.2
Total			372.73		303182240	24032360	19655620	346.87

WF_{mean}= average water footprint at end-of-life time by Mekonnen and Hoekstra (2012)

The water footprint components of crop water consumption (m³/ha) are values dependent on the green and blue water needs of the crop during its growing season (crop water consumption ET, mm). Green crop water consumption is the amount of crop water consumption covered by effective rainfall. Green and blue plant water consumption values are calculated by using the relationships between the amount of water used by the plant, effective rainfall, and net irrigation water requirement as specified in the Lovarelli et al., 2016 literature.

Blue crop water consumption (dn, ETblue-theoretical) theoretically represents the amount of irrigation water needed by the crop. This amount includes the water losses that occur as the irrigation water delivery from the water source to the crop. Therefore, blue crop water consumption has been divided by the irrigation efficiency (E) to calculate the total theoretical irrigation water requirement using equations 1 (Hoekstra et al., 2012).

$$ET_{blue\text{-}theoretical} = ET_{blue}/E \quad (1)$$

Crop water use (CWU, m^3/ha) represents the total evapotranspiration amount (ET) during the crop growing season (lgp) and is determined by equations 2.

$$CWU_{green/blue} = 10 \times \sum_{d=1}^{lgp} ET_{green/blue} \quad (2)$$

The water footprint of crops is obtained from the sum of green, blue, and grey water footprint components throughout the crop growth process by equations 3. Green and blue water footprints (m^3/ton) are calculated by dividing crop water use (m^3/ha) by crop yield (ton/ha) using equationss 4 and 5. The green, blue, and total water footprint values during the growing season were calculated using equationss 6, 7 and 8, based on the total volume of water used for crop production (Hoekstra et al., 2011). Grey water footprint for crop production has been calculated using the average water footprint per ton of commodity per country, weighted based on origin (WF* in m^3/ton) values described in Mekonnen and Hoekstra (2011).

$$WFproc = WFproc\text{-}green + WFproc\text{-}blue + WFproc\text{-}grey \quad (3)$$

$$WFproc\text{-}green = \frac{CWU_{green}}{Y} \quad (4)$$

$$WFproc\text{-}blue = \frac{CWU_{blue}}{Y} \quad (5)$$

$$WFproc\text{-}green\ (m^3) = wFproc\text{-}green\ (m3/ton) \times Production\ (ton/year) \quad (6)$$

$$WFproc\text{-}blue\ (m^3) = wFproc\text{-}blue\ (m^3/ton) \times Production\ (ton/year) \quad (7)$$

$$WFgrey\ (m^3) = wFproc\text{-}grey\ (m^3/ton) \times Production\ (ton/year) \quad (8)$$

The water footprint of livestock includes the total amount of water used directly or indirectly in the production of beef, dairy, and other products from cattle, sheep, and poultry raised in the region. In animal production, the blue water footprint per animal is obtained by multiplying the number of livestock (HSi,j) by average water footprint at end of life time (HSUi,j, m^3/animal) reported by Mekonnen and Hoekstra (2012) using equations 9.

$$BlueSA_{animal} = \sum HS\dot{I}, \times HSUi,j \quad (9)$$

The blue, green, and grey water footprints of animal products such as meat, milk, and eggs were obtained by multiplying the water footprint values per ton described by Mekonnen and Hoekstra (2012) with the total production quantities in Bilecik province.

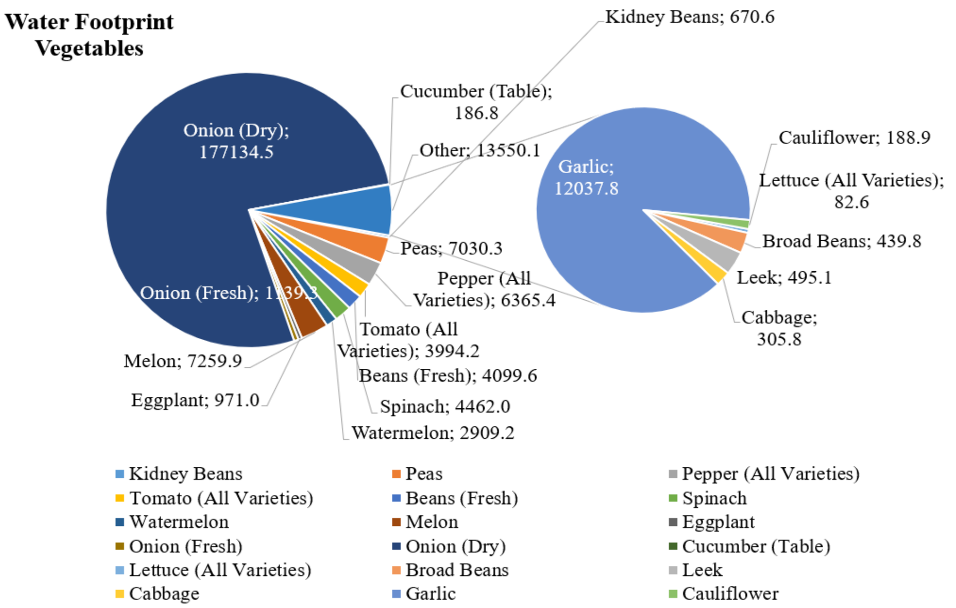

Figure 3. Water footprint of vegetables.

Table 3. The green, blue and grey water footprint along process of growing crops

Crop Category	Crop variety	Cultivated area (ha)	Crop Production (ton/year)	WFproc-green (m3/ton)	WFproc-blue (m3/ton)	WFgreen (m3)	WFblue (m3)	WFgrey (m3)	WFproc (million m3)
Field Crops	Wheat	192782.00	45772.40	377.52	1158.66	17279771.55	53034770.55	8788300.64	79.10
	Barley	14496.10	3089.48	338.87	1197.76	1046925.33	3700453.05	71057.96	4.82
	Rye	60.00	11.84	313.82	1357.89	3716.24	16080.33	1717.11	0.02
	Oat (Green Grass)	2015.00	79.76	62.94	228.79	5019.97	18248.71	11565.32	0.03
	Dried Beans	83.30	44.48	849.02	3833.94	37764.43	170533.71	11075.54	0.22
	Chickpeas	206.60	92.19	709.49	1767.03	65407.28	162901.15	35308.43	0.26
	Sunflower (Oil)	170920.60	87059.73	809.88	4563.85	70507836.78	397327180.85	12275422.54	480.11
	Corn (Silage)	4135.50	87.20	33.53	160.67	2923.28	14009.70	14300.29	0.03
	Sainfoin (Green Grass)	6.00	0.26	69.13	155.65	18.03	40.60	28.70	0.00
	Alfalfa (Green Grass)	1807.40	37.44	116.31	115.38	4354.74	4319.84	1123.19	0.01
	Triticale	520.40	114.12	348.69	1508.79	39793.63	172188.77	43709.48	0.26
	Sugar Beet	221.80	3.09	44.94	131.89	139.03	408.03	1184.87	0.00
	Canola	8944.80	2789.24	769.90	973.53	2147451.11	2715408.00	694521.61	5.56
	Paddy	68.60	10.31	370.97	1499.82	3823.75	15459.15	1979.01	0.02
	Lentil	2855.10	2676.66	1490.63	4500.00	3989890.72	12044953.13	1025159.34	17.06
	Sorghum (Green Grass)	19.00	0.66	111.10	117.10	72.79	76.72	125.79	0.00
	Triticale (Green Grass)	59.00	2.36	128.62	152.33	302.92	358.77	902.05	0.00
	Meadow Grass	833.40	36.64	246.84	285.30	9043.26	10452.50	7034.22	0.03
	Peas (Fodder)	1205.50	45.54	93.28	136.84	4248.12	6231.95	17442.95	0.03
	Total	54240.20	141953.39	7285.46	23845.23	95148502.97	469414075.52	23001959.02	587.56
Vegetables	Kidney Beans	5.50	0.58	72.63	303.19	151.92	494.82	23.85	0.00
	Peas	83.60	8.10	177.68	461.71	1936.95	3076.84	2016.51	0.01
	Pepper (All Varieties)	87.70	6.14	293.45	675.31	1062.46	2513.92	2789.01	0.01
	Tomato (All Varieties)	204.50	6.43	68.95	274.85	498.70	1361.78	2133.75	0.00
	Beans (Fresh)	64.10	6.09	28.98	113.23	1427.21	2544.58	127.83	0.00
	Spinach	68.80	6.33	198.80	530.40	925.46	663.54	2872.97	0.00
	Watermelon	723.80	16.93	165.70	15.11	978.12	1236.81	694.27	0.00
	Melon	284.00	14.06	30.78	62.89	1718.93	4345.71	1195.22	0.01
	Eggplant	38.80	1.99	80.05	273.88	251.00	551.21	168.82	0.00
	Onion (Fresh)	15.50	2.18	59.86	191.75	759.86	289.91	89.55	0.00
	Onion (Dry)	742.60	109.92	74.88	59.52	40169.62	133117.79	3847.10	0.18
	Cucumber (Table)	37.60	0.98			63.21	102.96	20.60	0.00
	Lettuce (All Varieties)	53.30	1.85	259.20	12.25	48.20	-4.35	38.76	0.00
	Broad Beans	19.00	1.97	63.60	17.94	325.65	45.06	69.04	0.00
	Leek	26.30	1.69	4118.80	1.39	268.50	82.87	143.75	0.00
	Cabbage	59.00	1.88	50.00	1.80	148.16	80.53	77.15	0.00
	Garlic	80.10	11.22	2.30	133.04	3878.17	7699.79	459.89	0.01
	Cauliflower	12.70	0.65	3115.80	12.07	81.57	52.27	55.06	0.00
	Total	2606.90	198.98	2600.30	1.59	54693.68	158256.04	16823.14	0.23
Orchards	Cherry	259.20	21.17	263.12	442.29	5569.51	9362.03	1799.21	0.02
	Peach and Nectarine	63.60	3.55	179.60	336.45	636.69	1192.75	301.33	0.00
	Olive (Oil)	4118.80	2959.10	2314.80	1606.43	6849734.92	4753571.47	251523.40	11.85
	Olive (Table)	50.00	27.78	1790.00	4242.22	49722.22	117839.51	2361.11	0.17
	Sour Cherry	2.30	0.02	24.22	39.21	0.42	0.68	1.47	0.00
	Grape	3115.80	258.20	267.00	196.90	68941.65	50839.65	21947.33	0.14
	Walnut	2600.30	1637.97	2029.59	5754.93	3324424.90	9426426.41	139227.86	12.89
	Quince	38.90	1.27	105.06	187.69	133.26	238.06	107.81	0.00
	Apple	340.70	6.27	59.29	102.98	371.74	645.64	532.92	0.00
	Plum	29.40	0.59	65.06	119.05	38.62	70.68	50.46	0.00
	Pomegranate	18.90	1.55	263.62	686.95	407.65	1062.27	131.44	0.00
	Pear	318.40	14.64	148.14	282.12	2168.73	4130.14	1244.36	0.01
	Apricot	20.20	0.94	149.28	273.16	139.70	255.65	79.55	0.00
	Strawberries and Blackberries	8.3	0.50	193.79	246.35	96.74	122.98	42.43	0.00
	Almonds	239.20	55.88	752.64	1157.69	42054.18	64686.69	4749.43	0.11
	Dates	8.30	0.39	150.24	270.26	58.15	104.60	32.90	0.00
	Total	11232.30	4989.80	8755.45	15944.67	10344499.07	14430549.20	424133.02	25.20
	Total Water Footprint of the process of growing crops. WFproc. million m3								612.99

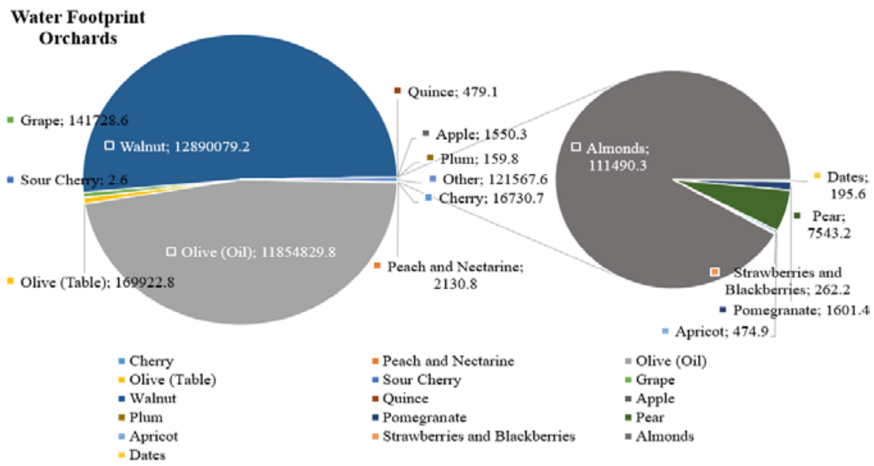

Figure 4. Water footprint of orchards.

3. Results

The total values of the water footprint of crop production, animal husbandry and general agricultural production in Tekirdağ province for 2022 are given in detail in Tables 1 and 2. The water footprint of crop production is calculated as 0.613 billion m^3, the water footprint of animal husbandry as 0.720 billion m^3 and the total agricultural water footprint as 1.33 billion m^3. Crop production water footprint share is 46% and animal production water footprint share is 54%. The distribution of crop production water footprint is as follows: green water footprint 17%, blue water footprint 79% and grey water footprint 4%. A summary of the distribution of the total water footprint of crop production among different crop groups and crops in the province is shown in Figure 2, 3 and 4. Based on the graph, field crops have the largest total water footprint in the province with 588 million m^3, followed by fruits with 25 million m^3 and vegetables with 0.23 million m^3. The total water potential of the province in 2022 is reported as 374.7 million m^3 by the State Hydraulic Works (DSI). Even excluding the green water footprint in crop production, the sum of blue and grey water footprints is calculated as 410.3 million m^3.

In animal production, the water footprint calculated according to the water requirement per animal is 372.7 million m^3 in total, while the water footprint of animal products such as milk, eggs, chicken meat and veal is calculated as 346.8 million m^3. The total water footprint of animal production is 719.6 million m^3. Considering the total water footprint of animal product production, the share of green water footprint is 93%, blue water footprint is 4% and grey water footprint is 3%.

4. Discussion

When previous studies are analysed, it is seen that agricultural production has the largest share among the components of the water footprint. On a global scale, agricultural production accounts for 70% of water use and 90% of indirect water use. In Türkiye, agricultural production accounts for 74% of direct water use, which can be as high as 86% in arid regions with continental climates (DSI, 2022).

Alongside the intensity of water use for agricultural purposes, rainfall anomalies are increasing in the gateway regions where the study was conducted. In addition to classical methods to examine how water is used, the use of techniques such as water footprint, which can distinguish between more uses and assess the impacts on the ecosystem, has increased especially in the last decade. There is a need for detailed studies on the agricultural sector, which is the main user of water in our country and in the world (Ababaei and Etedali, 2017; Novoa et al., 2019; Hossain et al. 2021; Yang et al., 2020; Cai et al., 2022). This situation is similar to the official institutional statistics where water use is announced and reveals the reliability of the study results.

The water footprint method can be used robustly and reliably to assess the impacts of crop and livestock production on water resources, either in watersheds or in specific production regions. This method provides a good description of the responses of crop and livestock production (Novoa et al., 2019; Yang et al., 2020, Gedik et al. 2023). In the study, field crops, vegetables and fruit cultivation and similar groups were analysed and total water footprint values of 390.16, 56.72, 8.10 and 152.84 million m^3 were obtained, respectively. It is seen that the values are high in field crops and fruit cultivation. This situation is similar to the production statistics and the results of other studies. In the study conducted by Novoa et al. in 2019, the agricultural water footprint was obtained as 18,221 m^3. In the study where water footprints were calculated, the highest values were reached in the Thames, Scheldt, Rhine and Po basins, which are the main river basins in Europe, and the water footprint values were 130,363 m^3 /km^2, 200,524 m^3 /km^2, 109,720 m^3 /km^2 and 219,630 m^3 /km^2, respectively (Vanham and Bidoglio, 2014). In another study, Cai et al. (2022) examined the agricultural water footprint in China between 2000 and 2017 and the average value was explained as 5.039 x 109 m^3/year. In the study by Çakmak and Torun (2023), agricultural water footprint for irrigation networks in the Konya closed basin in our country was evaluated. The agricultural water footprint in the Konya Closed Basin was calculated as 1.09 million m^3/ha. Muratoğlu (2020) calculated the average agricultural water footprint value as 3.43 billion m^3/year in his study to evaluate the agricultural water footprint and utilization in Diyarbakır. Erdem (2021) conducted a water footprint assessment for the Seyhan, Ceyhan and Asi Basins. The water footprint values in these basins were calculated as 3.53, 6.58 and 2.51 billion m^3 respectively. When the studies and data obtained are examined, it is seen that water footprint data vary according to the plants grown in the relevant region, plant planting rates, agricultural techniques, irrigation methods, and are also significantly affected by arid and normal precipitation conditions. The fact that it depends on many natural and artificial parameters is considered as a positive factor in reflecting natural conditions.

In addition to sectoral data, the water footprint concept includes green, blue and grey water footprint components. The components reflect the utilization characteristics of water resources more accurately and reliably. Studies show that the total water footprint of crop production varies between 2.13 and 114.79 billion m^3, while the total water footprint of animal production is between 0.43 and 9.98 billion m^3 (Çakmak and Torun, 2023; Erdem, 2021; Muratoğlu, 2020; Ahi and Çakmak, 2023). The results obtained under similar conditions in the literature by Egea et al. (2024), Cai et al. (2022), Yang et al. (2020), Hossain et al. (2021), Novoa et al. (2019), Ababaei and Etedali (2017) and Lovarelli et al. (2016).

5. Conclusion

In conclusion, the water footprint analysis for Tekirdağ province in 2022 highlights the significant role of agricultural activities in water resource utilization, with crop production accounting for 54% and animal husbandry for 46% of the total agricultural water footprint. The results underscore the substantial contributions of field crops and fruit cultivation to water consumption, consistent with global and regional studies. Furthermore, the green, blue, and grey water footprint components provide a nuanced understanding of water resource utilization, with variations influenced by factors such as crop type, agricultural techniques, and climatic conditions. These findings emphasize the importance of adopting sustainable water management practices and innovative agricultural methods to optimize water use efficiency. Future studies should further explore the impacts of rainfall anomalies, irrigation technologies, and policy interventions to mitigate the strain on water resources, particularly in regions with high agricultural activity and limited water availability. This comprehensive approach is vital to ensure the sustainable development of the agricultural sector and the preservation of critical water resources.

Author Contributions

The percentages of the authors' contributions are presented below. All authors reviewed and approved the final version of the manuscript.

	H.T.G.	Y.A.	B.Ç.
C	70	20	10
D	80	10	10
S	30	40	40
DCP	90	5	5
DAI	70	15	15
L	100	-	-
W	80	10	10
CR	50	20	30
SR	100	-	-
PM	100	-	-
FA	100	-	-

C= concept, D= design, S= supervision, DCP= data collection and/or processing, DAI= data analysis and/or interpretation, L= literature search, W= writing, CR= critical review, SR= submission and revision, PM= project management, FA= funding acquisition.

Conflict of Interest

The authors declared that there is no conflict of interest.

Ethical Consideration

Ethics committee approval was not required for this study because there was no study on animals or humans.

References

Ababaei B, Etedali H.R. 2017. Water footprint assessment of main cereals in Iran. Agric Water Manag, 179: 401-411.

Ahi Y, Çakmak B. 2023. Sürdürülebilir Kentsel Su Yönetimi: Ankara İli Su Ayak İzi Yaklaşımı. In: Öktem MK, Çiftçi L, editors. Sürdürülebilirlik, Kent ve Doğa. Gazi Yayınevi Ankara, Türkiye, 1st ed., pp: 97-127.

Anonymous. 2023a. Republic of Türkiye Ministry of Environment, Urbanization and Climate Change Tekirdağ Province 2016 Environmental Status Report (in Turkish).

Anonymous. 2023b. Republic of Türkiye Ministry of Agriculture and Forestry Tekirdağ Provincial Directorate 2022 Report (in Turkish).

Cai J, Xie R, Wang S, Deng Y, Sun D. 2022. Patterns and driving forces of the agricultural water footprint of Chinese cities. Sci Total Environ, 843: 156725.

Chapagain AK, Hoekstra AY. 2004. Water footprints of nations. Value of Water Research Report Series; No. 16. Unesco-IHE Institute for Water Education.

Chapagain AK, Hoekstra AY, Savenije H.H.G., Gautam, R. 2006. The water footprint of cotton consumption: An assessment of the impact of worldwide consumption of cotton products on the water resources in the cotton producing countries, Ecol Econ, 60(1): 186-203.

Çakmak B, Torun E. 2023. Evaluation of agricultural water footprint in Konya closed basin irrigation schemes. Harran J Agric Food Sci, 27(2): 239-252.

DSI. 2022; General Directorate of State Hydraulic Works, Provincial Directorate 2022 Report (in Turkish).

Egea G, Castro-Valdecantos P, Gómez-Durán E, Munuera T, Domínguez-Niño JM, Nortes PA. 2024. Impact of Irrigation Management Decisions on the Water Footprint of Processing

Tomatoes in Southern Spain. Agronomy (Basel), 14(8): 1863.
Ercin AE, Hoekstra AY. 2012. Carbon and water footprints: Concepts, Methodologies and Policy Responses. UNESCO.
Erdem E. 2021. Agricultural Water Footprint Analysis in Seyhan, Ceyhan and Asian Basins. MSc Thesis, Batman University, Postgraduate Education Institute, Batman, Türkiye, pp: 67.
Gedik C, Gürdil, GA, Demirel B. 2023. Evaluation of Plant Residues: Samsun Province. BSJ Agri, 6(6): 694-699.
Hoekstra AY, Chapagain A, Martinez-Aldaya M, Mekonnen M. 2011. The Water Footprint Assessment Manual: Setting the Global Standard, Earthscan publications, ISBN 978-1-84971-279-8 (hardback).
Hoekstra AY, Booij MJ, Hunink JC, Meijer KS. 2012. Blue water footprint of agriculture, industry, households and water management in the Netherlands: An exploration of using the Netherlands Hydrological Instrument, Value of Water Research Report Series No. 58, UNESCO-IHE, Delft, the Netherlands.
Hossain I, Imteaz M.A., Khastagir A. 2021. Water footprint: applying the water footprint assessment method to Australian agriculture. J Sci Food Agric, 101(10): 4090-4098.
Lovarelli D, Bacenetti J, Fiala M. 2016. Water Footprint of crop productions: A review. Sci Total Environ, 548: 236-251.
Mekonnen M, Hoekstra AY. 2011. National water footprint accounts: The green, blue and grey water National water footprint accounts: The green, blue and grey water footprint of production and consumption. Volume 1: Main Report. URL: https://digitalcommons.unl.edu/wffdocs (accessed date: May 17, 2024)
Mekonnen MM, Hoekstra AY. 2012. A Global Assessment of the Water Footprint of Farm Animal Products. Ecosyst, 15(3): 401– 415.
Muratoğlu A. 2020. Assessment of water footprint of production: A case study for Diyarbakır province. Gazi Uni Fac Engin Archit J, 35(2): 845-858.
Novoa V, Ahumada-Rudolph R, Rojas O, Sáez K, De La Barrera F, Arumí J.L. 2019. Understanding agricultural water footprint variability to improve water management in Chile. Sci Total Environ, 670: 188-199.
TSI. 2024. Turkish Statistical Institute database for Tekirdağ Province data's. URL: https://biruni.tuik.gov.tr/medas/?kn=92&locale=tr (accessed date: November 02, 2024)
TSMS. 2022. Turkish State Meteorological Service, Tekirdağ Provincial Meteorological Data Records.
UN-Water 2024. Water and Climate Change. URL: https://www.unwater.org/water-facts/water-and-climate-change (accessed date: November 02, 2024)
WMO. 2021. World Meteorological Organization 2021 State of Climate Services
WMO. 2023. State of global water resources report 2023. WMO-No.1362, New York, USA, pp: 80.
Vanham D, Bidoglio G. 2014. The water footprint of agricultural products in European river basins. Environ Res Lett, 9(6): 064007.
Yang H, Long A, Zhang P, Deng X, Li J, Deng M. 2020. Evaluating agricultural water-use efficiency based on water footprint of crop values: a case study in Xinjiang of China. J Arid Land, 12, 580-593.

Black Sea Journal of Agriculture
doi: 10.47115/bsagriculture.1624433

Open Access Journal
e-ISSN: 2618 – 6578

Research Article
Volume 8 - Issue 2 : 194-204 / March 2025

PRODUCTION AND MARKETING OF WALNUT IN ÇAĞLAYANCERİT DISTRICT OF KAHRAMANMARAŞ PROVINCE

Zülküf AYDEMİR[1]*, Akide ÖZCAN[2], Mehmet AYTEKİN[3]

[1]*Gaziantep University, Institute of Social Sciences, Department of Business Administration, 27100, Gaziantep, Türkiye*
[2]*Kahramanmaraş Sütçü İmam University, Göksun Vocational School, Department of Organic Agriculture, 46500, Kahramanmaraş, Türkiye*
[3]*Gaziantep University, Faculty of Economics and Administrative Sciences, Department of Business Administration, 27100, Gaziantep, Türkiye*

Abstract: This study was conducted to evaluate the current situation of walnut production and marketing in Çağlayancerit district of Kahramanmaraş province, which has an important place in terms of walnut cultivation in Türkiye. Within the scope of the study, secondary source walnut production data of Turkish Statistical Institute (TURKSTAT) were used. In addition, verbal interviews were conducted with producer and NGOs. In the research, SWOT analysis was conducted by examining the secondary data of producer and NGOs. Walnut production in Çağlayancerit increased from 520 decares in 2004 to 35,000 decares in 2023. The increase in walnut production area between these years is calculated as 149%. According to 2023 data, approximately 6,750 tonnes of shelled walnuts was produced in 35,000 decares. With these values, Çağlayancerit is the district with the highest walnut production area and amount among the 11 districts of Kahramanmaraş. Interviews with professional chambers and local people revealed that the walnut genotype, which has been cultivated in the region for many years, was registered by selection breeding and included in the National variety list by the Central Directorate of Seed Registration and Certification of the Ministry of Agriculture and Forestry of the Republic of Türkiye in 2009 under the name of 'Maraş 18'. While 'Maraş 18' variety was known only by the people of the region before 2009, today it has become a variety known all over Türkiye and even the world. As a result of the SWOT analysis of the interviews with the NGOs and producers of the region; being in a good geographical location in walnut production, being in the position of walnut gene centre, carrying out production activities according to the land conditions, having academic experts in the region on walnut production and cooperation can be considered as strengths. When we look at the weaknesses; climate change, global warming, decrease in groundwater in recent years, deterioration of the ecological balance of the region, spread of plant diseases and pests, increase in input costs, decrease in the number of experienced farmers, lack of cooperatives and unions, insufficient promotion of the district walnut. For Çağlayancerit walnut production and marketing to gain momentum, it will be beneficial to increase the regional incentive investments by the state and private sector and increase the number of cooperatives/unions. The active use of the existing walnut processing and packaging facility will also contribute to the branding process of the walnut in the region. In addition, it is thought that the recognition of the region with this variety will increase by focusing on the advertising and marketing activities of the name 'Maraş 18' in the domestic and foreign markets.

Keywords: Çağlayancerit, Walnut, Production, Marketing

***Corresponding author:** Gaziantep University, Institute of Social Sciences, Department of Business Administration, 27100, Gaziantep, Türkiye
E mail: zaydemir@ksu.edu.tr (Z. AYDEMİR)
Zülküf AYDEMİR https://orcid.org/0000-0003-0393-4557
Akide ÖZCAN https://orcid.org/0000-0001-7182-3811
Mehmet AYTEKİN https://orcid.org/0000-0001-5464-0677

Received: January 23, 2025
Accepted: February 25, 2025
Published: March 15, 2025

Cite as: Aydemir Z, Özcan A, Aytekin M. 2025. Production and marketing of walnut in Çağlayancerit district of Kahramanmaraş province. BSJ Agri, 8(2): 194-204.

1. Introduction

Walnut (*Juglans regia* L.) is one of the temperate climate fruits in the *Juglandaceae* family. There are approximately 60 different species of walnut worldwide, 21 of which belong to the genus Juglans (Ahmad et al., 2018). The origin of walnut is thought to be in the Ghilan region of Iran on the Caspian Sea coast. However, J. regia, which is native to Central Asia, grows naturally and is cultivated in a wide area from the southern parts of the former Soviet Union to China, the Eastern Himalayas, Southeastern Europe and the Caucasus (Britton et al., 2007). Today, walnut is widely grown all over the world except in tropical regions. It is believed that historical migrations, trade caravans and natural spread have greatly contributed to the widespread distribution of walnuts as a fruit species (Budak, 2010).

According to the World Food and Agriculture Organization (FAO), 5.274.025 tonnes of shelled walnuts were produced from a total area of 1.604.593 hectares worldwide in 2022. In walnut production, China is the world leader with 1.400.000 tonnes of walnut in shell on 356.656 hectares. China (47%) and USA (23%) realize more than half of the world's walnut production. Iran ranks third with 12% production, while Türkiye ranks fourth with 11% (FAO, 2024).

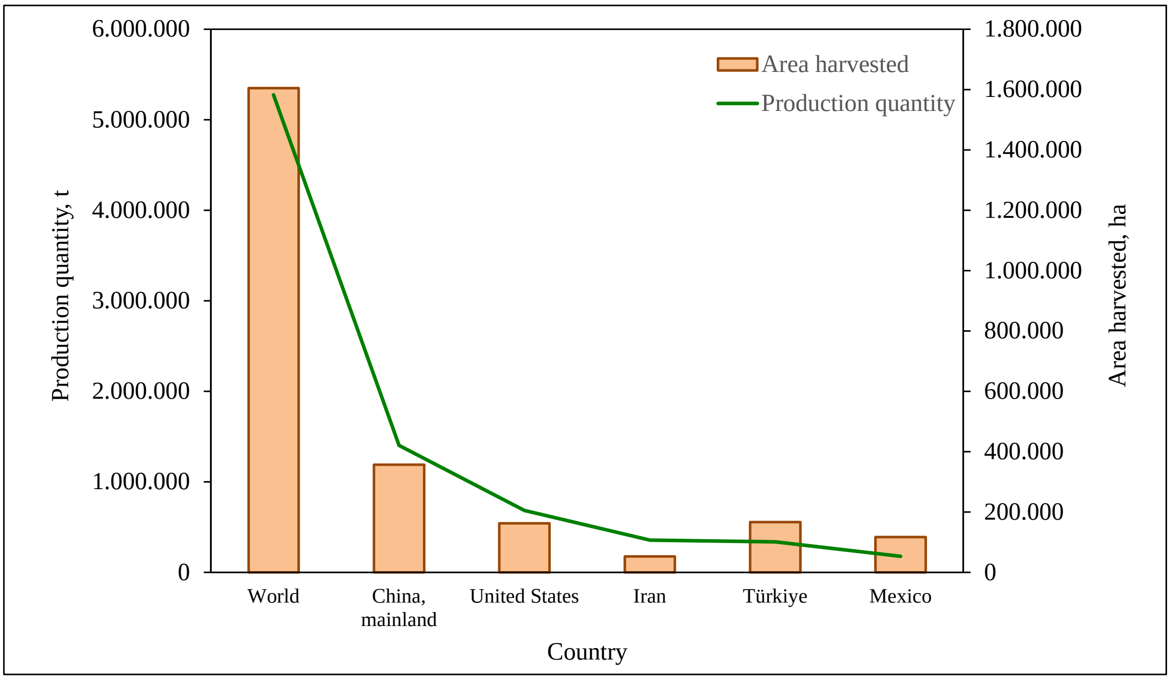

Figure 1. Production amount and area of 5 world walnut-producing countries (FAO, 2024).

Walnut is considered a dried fruit with high nutritional value (Güvenç and Kazankaya, 2019; Özcan et al., 2020, Arcan et al., 2021). Walnut kernel contains approximately 65% to 70% unsaturated fatty acids and 14% to 16% protein (Özcan and Sütyemez, 2019; Sütyemez et al., 2022). Walnut contains minerals such as iron, zinc, copper, magnesium, phosphorus and potassium (Yıldız and Sümbül, 2019). Walnut plays an important role in brain health, brain development and learning processes of children thanks to the silver ions it contains (Vural, 2021). Walnut is reported to prevent blood clotting, reduce the risk of coronary heart disease, reduce triglyceride and cholesterol levels, provide high energy and support metabolism by facilitating digestion. In addition, the green husk of walnut is used in the pharmaceutical and chemical industry (Şahin, 2005; Ketenci and Bayramoğlu, 2018; Anonymous, 2024a;b).

Different components of walnuts are used in various sectors. Both the shell and the wood of the walnut are utilized in various applications. Due to its hard, durable structure, walnut wood is a valuable timber material in furniture and parquet production. In regions such as Kahramanmaraş, walnut wood is especially used in the traditional art of carving. This art is considered as an important cultural heritage with its hand workmanship and detailed carving techniques (Çalış, 2014; Polat and Dindaroğlu, 2014). Walnut shells, kernels, and leaves are valuable raw materials. Walnut kernels are primarily used for walnut oil production, while walnut leaves find applications in the production of industrial products such as paints, paint solvents, and abrasives. Additionally, walnut leaves are known to have applications in traditional medicine due to their potential therapeutic properties.

In addition to being consumed as a snack, the kernel of walnut is used in many dishes, salads and desserts. Many food products such as walnut 'Sucuk', 'Pestil', 'Samsa', 'Köme', jam, walnut bread, and cakes constitute a wide range of walnut use. Walnuts, especially used in baklava production, has become an indispensable component of traditional desserts in Türkiye (Özçağıran et al., 2007; Şen, 2011; Yücer, 2013; Bou Abdallah et al., 2016; Şimşek and Gürsoy, 2016; Vural, 2021).

In Türkiye, walnut was cultivated as a border marker in home gardens or field edges in the past years, but nowadays, interest in this species has increased and modern orchards have been established and conscious cultivation has started to be carried out (Sütyemez, 2000; Haskınacı, 2003). Walnut production is an important source of livelihood for people living in rural areas. Walnuts are also important as an export product for countries. Countries with significant shares in walnut exports can earn foreign currency by exporting walnuts and positively contribute to their foreign trade balance. Walnut cultivation can become a sustainable agricultural policy when it is managed properly (such as an orchard) with the support of experts in the field. Thus, high-yielding products can be obtained with a minimum cost ratio.

In terms of agricultural income source and local economic development, walnut is known as an agricultural product with high returns. For this reason, it economically contributes raw materials to different sectors, especially the agricultural sector. The processing of products obtained from walnuts (nut, timber, etc.) supports the development of local businesses and the service sector and strengthens local communities (Unions, Cooperatives, Professional Chambers, etc.). Thus, the national and international marketing of walnuts significantly contributes to the development of the local economy (Hisarlı, 1989; Ketenci and Bayramoğlu, 2018).

The walnut production conditions of Kahramanmaraş province and its districts, which have an important place in walnut production activities in Türkiye, were examined in detail in this study. This study was conducted to identify the challenges faced in walnut production and marketing in the Çağlayancerit district of Kahramanmaraş, a key region for walnut production in Türkiye, and to propose potential solutions.

2. Materials and Methods

In this study, walnut production data for the year 2023 from the Turkish Statistical Institute (TURKSTAT) and walnut import-export data for the year 2022 from the Food and Agriculture Organization (FAO) were utilized. Additionally, secondary data from the producer and NGOs were examined and a SWOT analysis was conducted. Within the scope of the findings, the current and future status of walnut production and marketing in the Çağlayancerit district of Kahramanmaraş province was evaluated.

3. Results and Discussion

Walnut, which has a geographical history, distribution area and commercial importance, is widely produced in a large part of Europe and Asia. Türkiye is among the gene centre's of walnut (Sütyemez and Eti, 2001; Ketenci and Bayramoğlu, 2020).

Türkiye is an important country with a large production area in walnut cultivation. Walnut production in Türkiye is carried out in almost all regions. Türkiye's walnut production area in 2019 was approximately 1 million 246 thousand decares and 225 thousand tonnes of production was realized. The walnut cultivation area is determined to be 1 million 741 thousand decares by 2023. There are approximately 30 million walnut trees in this area. 57% of these trees are bearing and 43% are non-bearing trees. In 2023, 360.000 tonnes of walnuts were produced in Türkiye (Figure 2). Although there has not been a great expansion in the production area of Türkiye over the years, it is seen that the increase in the amount of production is significant. The amount of walnut production is expected to increase significantly once the non-bearing trees reach maturity. However, Türkiye is still not self-sufficient in walnut production. For Türkiye, which is suitable for walnut cultivation, to become self-sufficient, proper planning is required. With this planning, we believe that we will be in a leading position in walnut production, just as we are with other fruit species such as cherry, hazelnut and apricot.

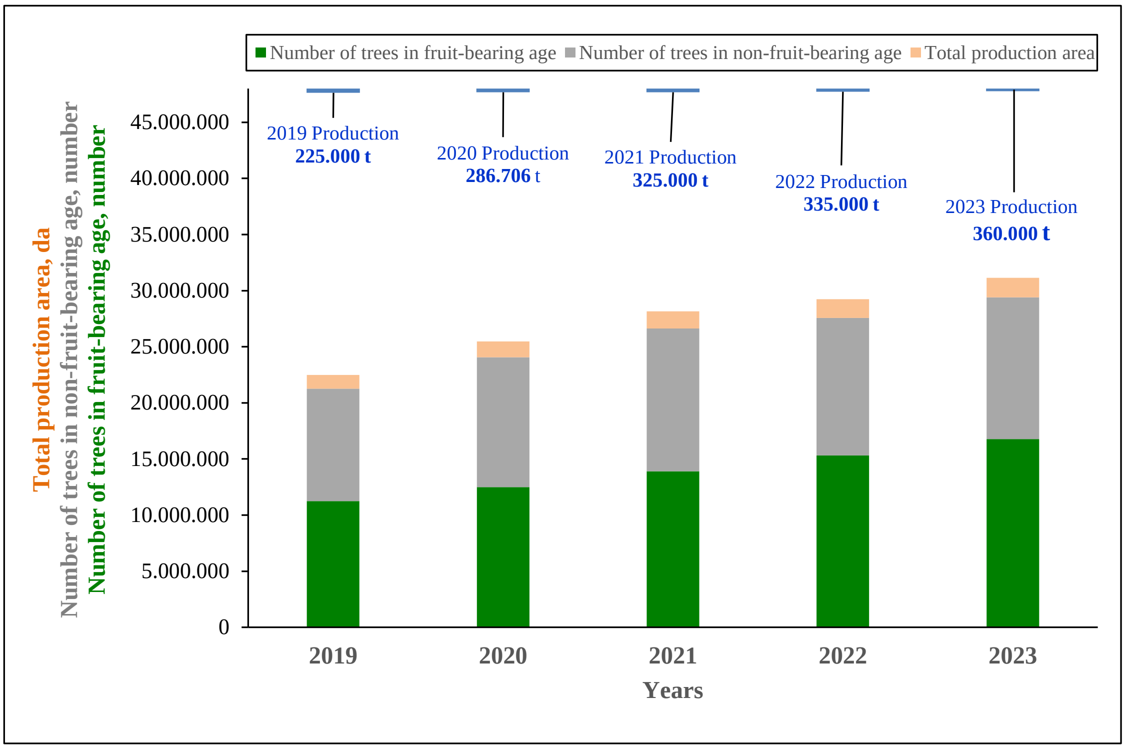

Figure 2. Walnut production values in Türkiye (TURKSTAT, 2024).

The density of walnut production by province in Türkiye for 2023 is shown in Figure 3, using color coding. When the map is examined, it is seen that walnut production is high in the Aegean, Marmara, Mediterranean, South Eastern Anatolia and Central Black Sea regions. At the provincial level, it is determined that 17 provinces produce more than 6.818 tonnes of walnuts. The highest production is in Kahramanmaraş, which holds an important position in Türkiye with 18.330 tonnes of walnut production. Bursa follows Kahramanmaraş with 18.018 tonnes of production. Bilecik ranks third with 17.800 tonnes, Denizli ranks fourth with 15.083 tonnes and İzmir ranks fifth with 14,785 tonnes (TURKSTAT, 2024). These data reveal that walnut cultivation is widespread in Türkiye and the intensive production in different provinces reveals the importance of the walnut industry throughout the country. The concentration of walnut production in various provinces emphasizes the potential and diversity of the walnut industry in Türkiye.

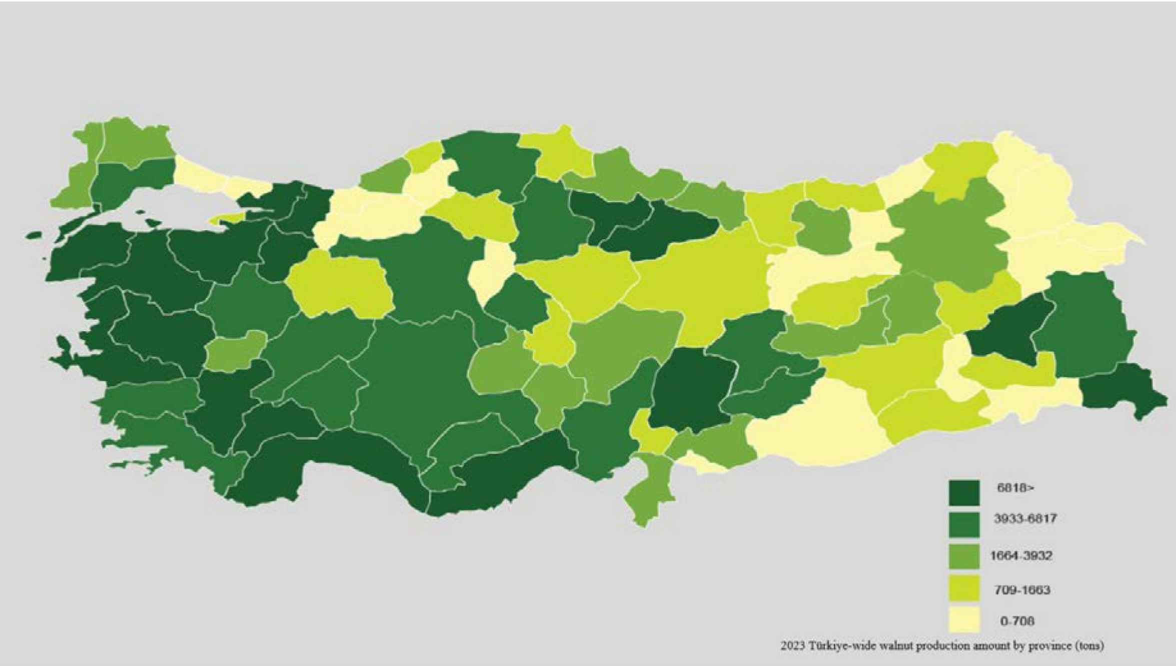

Figure 3. Walnut production map by provinces in Türkiye (2023).

World walnut export and import values in 2022 are presented in Table 1 and 2, respectively. The walnut trade in the world is carried out as nut and kernel nut. In 2022, approximately 528.000 tonnes of shelled walnuts were exported worldwide and a value of approximately $1,5 billion was obtained (Table 1). The United States holds the highest share in global in-shell walnut exports by value and is the world leader in these exports. The shelled walnut exports of our country are almost non-existent and the exports are not regular. Türkiye exported around 19,5 tonnes of shelled walnuts in 2022 and obtained $493.422.

Türkiye exports walnuts to countries such as Iraq, Azerbaijan, Syria, Egypt and Morocco. Türkiye is one of the largest markets for the USA, the world leader in shelled walnut production. The main reasons why The United States is the world leader in exports are that it attaches importance to standard walnut diversity consisting of orchards and has established the first producer association under the name of 'California Walnut Growers Association' as a solution to marketing and profitability problems (Hardesty, 2009). Türkiye ranks first among the walnut-importing countries in 2022. This indicates that Türkiye is a leading supplier in the global walnut trade and the USA is a major walnut exporter. Trade data show that the walnut industry is an important economic activity on an international scale and that trade between various countries is intensive (Kadakoğlu et al., 2022).

Table 1. World walnut export values in 2022

Nut			Kernel nut		
Countries	Value (000 $)	Production (tonnes)	Conturies	Value (000 $)	Production (tonnes)
USA	404514	11294766	Usa	882343	154002
Chile	261111	9048118	Mexico	465981	42261
China	188317	842032	Chile	213722	34891
UAE	153126	5851311	China	201038	44499
Mexico	61349	1333546	Ukraine	75308	20064
Türkiye	49396	1927393	Türkiye	54934	8228
World	1439422	52795930	World	2533093	420578

Table 2. World walnut import values in 2022

Nut			Kernel nut		
Countries	Value (000 $)	Production (tonnes)	Conturies	Value (000 $)	Production (tonnes)
Türkiye	160172	69779	Germany	348040	53134
UAE	145618	61464	Japan	114999	17997
Italy	86926	30527	Spain	140230	19414
Mexico	126254	31422	Korea	90402	14629
Iran	111717	38904	Netherlands	103549	16826
World	1077427	429463	World	1905327	330350

Türkiye's low competitiveness in walnut foreign trade is thought-provoking. Although Türkiye has been in the top five in the world ranking in walnut production for many years, it is still not a self-sufficient country. This situation is the result of repeating the mistakes made for years in walnut cultivation and not taking precautions.

Türkiye is one of the few countries in the world with a very high potential for cultivating horticultural crops and is recognized as the gene center for many fruit species (Kaşka et al., 2005).Walnut, which has an important place among these fruits, has important populations in various ecological regions of Türkiye (Bayazıt and Sümbül, 2012). However, although Türkiye is the gene center and homeland of walnut worldwide, it is not at a sufficient level in terms of production and export. The products produced cannot meet the domestic market consumption. In recent years, in addition to the incentives given by the state, the establishment of the orchards, the provision of consultancy services to farmers with experts on walnut production and the investment of the private sector in walnut cultivation have made walnut production more important (Özçağıran et al., 2007; Şen, 2011; Yücer, 2013; Ketenci and Bayramoğlu, 2018; Güvenç and Kazankaya, 2019).

In Kahramanmaraş, there are approximately 1 million 453 thousand walnut trees in an area of 110.385 decares as of 2023. While 62% of these walnut trees are fruit-bearing trees, 38% are non-fruit-bearing trees. In 2023, 18.330 tonnes of walnuts were produced in Kahramanmaraş. This value constitutes 5% of Türkiye's walnut production. The walnut tree area in Kahramanmaraş constitutes 6% of the total area of Türkiye. The average walnut yield per tree in Kahramanmaraş was determined as 20 kg/tree. This value is slightly below the average of Türkiye (22 kg/tree) (Table 3). The main reasons for Kahramanmaraş's walnut production being below the average in Türkiye are the high rate of sapling planting, the presence of young trees that have not yet produced fruit, insufficient maintenance in the orchards and some unconscious agricultural practices.

Table 3. Walnut production amounts by provinces in 2023 (TURKSTAT, 2024)

Provinces	Production amount (tonnes)	%	Production area (da)	%	Bearing (Number)	Non-Bearing (Number)	Yield per tree (kg/tree)
Kahramanmaraş	18330	5	110385	6	899350	553600	20
Bursa	18018	5	93779	5	671458	860430	27
Bilecik	17800	5	58043	3	671514	256257	27
Denizli	15083	4	127707	7	998894	977895	15
İzmir	15043	4	36262	2	412560	144078	36
Mersin	14785	4	36740	2	393012	126743	38
Çanakkale	14711	4	45062	3	531448	256651	28
Balıkesir	14332	4	101616	6	763726	909844	19
Tokat	12266	3	44754	3	565557	447736	22
Manisa	10338	3	113922	7	705421	1160939	15
Antalya	9681	3	24919	1	325839	127836	30
Burdur	9126	3	42488	2	413794	240009	22
Sakarya	8677	2	32804	2	330992	195640	26
Hakkâri	8147	2	25877	1	378845	241298	22
Amasya	7230	2	26644	2	287007	192405	25
Bitlis	7036	2	51240	3	258455	270370	27
Kocaeli	6849	2	20582	1	259525	83918	26
Van	6817	2	29719	2	222660	221120	31
Adana	5887	2	14814	1	246000	66148	24
Adıyaman	5711	2	25365	1	234802	73573	24
Total Province	225867	63	1062722	60	9570853	6245551	
Türkiye	360000	100	1740796	100	16777339	12627698	

Kahramanmaraş has 11 districts, two of which are in the center. Walnut cultivation is carried out in the agricultural lands of all districts. However, Çağlayancerit district has a different position from other districts in walnut cultivation. Because almost only walnut is grown in all orchards in the region. Almost all of the walnuts grown in the district are of a single variety (Maraş 18). According to TURKSTAT data of 2023, there are approximately 410.000 walnut trees in an area of 35.000 decares in Çağlayancerit. Of these walnut trees, 89% are fruit-bearing and 11% are non-fruit-bearing trees. In 2023, 6.750 tonnes of walnut was produced from this area. Çağlayancerit accounts for 37% of Kahramanmaraş walnut production and 32% of total planted walnut areas. The average walnut yield per tree in Çağlayancerit (18 kg/tree) is below the average of Kahramanmaraş (20 kg/tree) and Türkiye (22 kg/tree).

According to TURKSTAT data in 2023 (Table 4), Çağlayancerit district has the highest ratio in terms of the number of bearing trees and production area (da) compared to other districts of Kahramanmaraş. However, this situation is different in terms of production and yield per tree. It was determined that yield per tree (kg/ bearing) ratios were higher in Andırın and Afşin districts. It is predicted that these regions will make significant contributions to walnut production in the future. Nurhak district of Kahramanmaraş has the lowest production compared to other districts.

Table 4. Walnut production values of Kahramanmaraş districts in 2023 (TURKSTAT, 2024)

Districts	Production amount (tonnes)	Bearing (Number)	Non-Bearing (Number)	Production Area (da)	Yield per tree (kg/tree)
Çağlayancerit	6750	365000	45000	35000	18
Andırın	3559	110000	137000	9000	32
Dulkadiroğlu	2499	135150	50000	16335	18
Onikişubat	1372	87300	123010	15600	16
Pazarcık	1317	75000	29500	7800	18
Ekinözü	928	45650	13500	4050	20
Afşin	744	23000	37100	5500	32
Elbistan	536	29000	29000	6000	18
Türkoğlu	322	15150	24190	3000	21
Göksun	211	9100	56800	7100	23
Nurhak	92	5000	8500	1000	18

Information on walnut production (tonnes), the number of bearing and non-bearing trees (number), area of collective orchards (da), and yield per tree (kg) in Türkiye, Kahramanmaraş, and Çağlayancerit are provided in Table 4. When evaluated over the years, walnut production has increased both in Türkiye as a whole, in Kahramanmaraş province, and the Çağlayancerit district. While 126 thousand tonnes of walnut was produced in Türkiye in 2004, this figure increased to 360 thousand tonnes in 2023. Similarly, the amount of walnut production in Kahramanmaraş province, which was 4.836 tonnes in 2004 and 497 kg in Çağlayancerit district, has increased significantly in 2023. These rates have increased to 18.330, 6.750 tonnes in Kahramanmaraş and Çağlayancerit, respectively (Table 4).

The contribution of the scientifically identified/proven brand variety is very important in the acceleration of walnut production area and amount in Çağlayancerit in the last 10 years. A local genotype (Maraş 18) grown in the center and southern districts of Kahramanmaraş was selected by fruit breeder Prof. Dr. Mehmet SÜTYEMEZ at Kahramanmaraş Sütçü İmam University and adaptation studies were carried out for many years. This local genotype was registered as 'Maraş 18' in the national variety list by applying to the Seed Registration and Certification Centre Directorate of the Ministry of Agriculture and Forestry of the Republic of Türkiye in 2009. With this important step, the local genotype of Kahramanmaraş was taken under protection and became a variety known all over Türkiye. In addition to the existing orchards established with this variety in Çağlayancerit, new ones were established rapidly. The reasons for the preference of 'Maraş 18' walnut throughout the district are that the shelled fruit weight is approximately 13-15 g, the kernel weight is 7-9 g and the kernel percentage is between 53-57%. In addition, the fact that 'Maraş 18' nuts have a unique flavor is the most important feature that distinguishes the variety from other varieties. The variety is resistant to pests and the kernel is easily separated from the shell (Sütyemez, 2016).

Registration Year	2009
Breeding Method	Selection
Breeder	Mehmet Sütyemez
Some Plant Characteristics	
Tree Crown Structure	Semi-upright
First Leafing	Medium
Flowering	Protoandry
Yield	Intermediate
Harvest Time	Early
Leaf Fall	Early

Some Fruit Characteristics

Nut Weight	13-15g	Kernel Weight	7-9g
Fruit Size	Extra	Kernel Percentage	53-57%

Figure 4. Characteristics of Maraş 18 variety (Sütyemez, 2016)

Walnut production in Çağlayancerit increased from 520 decares in 2004 to 35.000 decares in 2023 (Table 4). It is calculated that there is a 149% increase in walnut production area from 2004 to 2023. When the number of bearing trees (number) is analyzed, there has been an increase in Türkiye (average 10.594.993), Kahramanmaraş (average 521.018) and Çağlayancerit (average 167.561). However, the number of non-bearing trees did not show a similar increase. The important reasons for this situation can be listed as the decrease in the areas where new orchards will be established in the region, extreme heat with climate change, the negative effects of drought, not finding enough irrigation water, and the increase in the presence of diseases/pests. In general, there have been fluctuations in walnut production in Türkiye, Kahramanmaraş and Çağlayancerit district. When the yield per tree (kg/tree) ratios are analyzed, there have been changes according to years (Table 5).

In the study conducted by Aytekin et al. (2022), as a result of the survey conducted with 90 walnut producers in the Çağlayancerit, 88,90% of the producers stated that they did not receive any training on walnut cultivation, 53,33% were members of a producer organization, 54,44% benefited from agricultural supports and 95,56% did not have agricultural insurance. In the same study, almost all of the producers (95,56%) stated that they benefited from the foreign labor force in walnut production and that they were satisfied with walnut prices (98,90%), and it was stated that the most important reason for the producers to produce walnut was the price and market advantages (77,78%). It was concluded that 44,44% of the producers sell their walnuts in the neighborhood market and 35,56% of them sell them through traders. The most important output of this study is that walnut is produced and marketed informally in the region. This situation causes a lack of accurate information about the real walnut potential of the region.

Marketing is defined as a set of processes and an organizational function for managing customer relationships, creating, promoting, and delivering value to customers in a way that benefits the business and its stakeholders (Gundlach and Wilkie, 2009). Philip Kotler defines marketing as a social and managerial process by which individuals and groups obtain what they need and want by creating, offering and exchanging valuable products with others (Akhmadi, 2018). In other words, marketing is the process of planning and executing the pricing, promotion and distribution of products/services to create exchanges that satisfy individual and organizational objectives. Marketing is the process of exchanging products and services between two parties, aiming to meet the needs and desires of customers while benefiting both parties (Girma and Abebe, 2019).

Agricultural marketing, on the other hand, is defined as all activities involved in the process starting with the quantity and quality of agricultural products to be produced by the farmer, preparing the products for market conditions, standardizing them according to market requirements, storing them properly, transporting, and ultimately delivering them to the consumer (Atay and Kartal, 2020). In other words, agricultural marketing brings together all the processes involved in transporting the products produced by farmers or producers from farms to final consumers and the people or institutions involved in the fulfillment of these processes. In this way, agricultural marketing constitutes one of the cornerstones of the economy.

Table 5. Comparison of Çağlayancerit walnut production (TURKSTAT, 2024)

	Years	Çağlayancerit	% Change	Kahramanmaraş	% Change	Türkiye
Production amount (tonnes)	2004	497	10.28	4836	3.84	126000
	2009	4060	38.64	10507	5.93	177298
	2014	4176	68.39	6106	3.38	180807
	2018	3835	36.47	10515	4.89	215000
	2020	3020	23.17	13036	4.55	286706
	2021	7250	37.69	19237	5.92	325000
	2022	7888	41.39	19059	5.69	335000
	2023	6750	36.82	18330	5.09	360000
Bearing (Number)	2004	9450	6.49	145700	3.47	4200000
	2009	29000	14.64	198025	3.81	5191724
	2014	74420	24.38	305250	4.36	7000897
	2018	116620	27.04	431270	4.37	9875068
	2020	151000	25.95	581850	4.66	12488338
	2021	290000	36.93	785300	5.65	13899362
	2022	305000	37.13	821400	5.36	15327219
	2023	365000	40.58	899350	5.36	16777339
Non-Bearing (Number)	2004	2800	8.59	32610	1.48	2200000
	2009	18000	38.39	46886	1.47	3200279
	2014	31236	20.09	155501	2.89	5374456
	2018	30725	8.25	372276	4.18	8896575
	2020	53500	12.02	445031	3.84	11579246
	2021	80000	14.37	556700	4.38	12719106
	2022	75000	12.87	582800	4.76	12245863
	2023	45000	8.13	553600	4.38	12627698
Collective orchards area (da)	2004	520	44.44	1170	0.70	168000
	2009	3600	56.40	6383	1.74	366736
	2014	6552	30.24	21670	3.12	693947
	2018	14527	24.85	58468	5.23	1117749
	2020	21000	26.73	78577	5.54	1417899
	2021	30000	30.92	97020	6.32	1535204
	2022	32000	30.06	106450	6.39	1664949
	2023	35000	31.71	110385	6.34	1740796
Yield (kg/ bearing)	2004	53	160.61	33	110.00	30
	2009	140	264.15	53	155.88	34
	2014	56	280.00	20	76.92	26
	2018	33	137.50	24	109.09	22
	2020	20	90.91	22	95.65	23
	2021	25	104.17	24	104.35	23
	2022	26	113.04	23	104.55	22
	2023	18	90.00	20	95.24	22

In the Çağlayancerit district of Kahramanmaraş province, it has been observed that farmers prefer walnut cultivation as an agricultural product because of the continuation of a habit from the past. In addition, in terms of cultivation/production techniques, having experienced individuals in the family who are interested in walnut production provides an important advantage. The favorable environmental conditions of the region for producing quality walnut fruits have also contributed to the increased cultivation of this species. The demand for walnuts from the local population, the ease of marketing the product, and the sales guarantee are other important factors. In addition, the walnut processing and packaging facility, which was supported by the Eastern Mediterranean Development Agency (DOGAKA) and became operational in 2022, is of great importance for the district. When the walnuts produced in the garden are brought to the facility and processed (separated from their shells, dried and sorted according to their quality), the added value will increase in the marketing of the product (Anonymous, 2024b). Therefore, the increase in the profit margin to be obtained can be considered as an opportunity for producers.

The preferred and cultivated walnut variety in Çağlayancerit is ‘Maraş 18’ by 99%. In addition, this variety is one of the European Union geographical indication registered products of Kahramanmaraş as Çağlayancerit Walnut (Anonymous, 2024c). Thanks to

'Maraş 18', it is expected that its competitiveness will increase both within the country and with international recognition, domestic demand and export potential will be strong, and it will be effective in the regional economy and employment.

In the walnut production and marketing process, it is known that the walnut sales made by small producers or women with their own resources significantly affect the official production data. Small producers and women usually grow walnuts in small quantities and sell them to their neighbors, families and tradesmen in local markets. However, these sales are usually not officially recorded. This shows that small producers and women play an important role in walnut production and are influential in non-market sales. Therefore, to improve production and marketing statistics and to obtain more accurate results, the role of small producers and women in walnut production should be supported and various policies, supports and plans should be developed. In addition, it is understood that the quantities of walnuts used during the production of products (sucuk, samsa, etc.) obtained from walnuts and called as syrup in the region are not recorded. The high amount of walnuts, which has an important place in the nutrition of the people of the region, is also allocated to households. Considering these circumstances, it is a fact that there was more production in the region than the records.

Vural (2021) reported that, although efforts have been made to increase walnut production, Türkiye is still not self-sufficient and imports have been increasing in each period as production cannot fully meet the demand.

Güvenç and Purlu (2022) examined walnut production in Türkiye and future production and demand forecasts. In the study, based on walnut production and demand data in Türkiye from 1999 to 2019, the production and demand for 2020-2045 were predicted. According to the results, an increase in walnut production and demand is expected between 2020 and 2045, and Türkiye is projected to become self-sufficient in walnuts during this period. In the study, based on walnut production and demand data in Türkiye between 1999-2019, the production and demand for the period 2020-2045 were predicted. According to the results, it is predicted that an increase in walnut production and demand is expected between 2020-2045 and Türkiye will become a self-sufficient country in walnuts in this period.

3.1. SWOT analysis

3.1.1. Strengths of walnut production in Çağlayancerit

1. In walnut production in Çağlayancerit, the local people can easily cultivate walnuts due to the district's geographical location, high altitude, and favorable weather conditions.

2. Walnut production in Çağlayancerit dates back to ancient times. Therefore, having elderly and experienced individuals in walnut production within the family is a great opportunity for future generations. Transferring experiences from father to son and from grandfather to grandson on walnut production,

3. Contributing to the economy by planting walnuts in idle areas based on the mountainous geographical structure of the district and experiences from the past,

4. The existence of incentive supports given to farmers by the state,

5. In recent years, private sector companies in Çağlayancerit and prominent farmers of the district have taken steps to invest in walnut orchards, and the interest in the orchard system has increased,

6. In Çağlayancerit, there is a walnut processing and packaging facility supported by DOGAKA and located in the district center,

7. In recent years, farmers have started to use modern technological tools (fertilization, spraying, irrigation, roasting machine),

8. People in the region market their walnuts as a known variety (brand) using the name 'Maraş 18',

9. Kahramanmaras Sutcu Imam University can be listed as having academicians who are experts in walnut production and marketing at the Faculty of Agriculture, as well as advising farmers.

3.1.2. Weaknesses of walnut production in Çağlayancerit

1. In recent years, due to climate change and global warming, the decrease in all water resources, especially underground water resources, and inadequate irrigation of walnut production areas,

2. Rapid spread of diseases/pests due to intensive walnut cultivation in the region and disruption of ecological balance,

3. Although walnut cultivation has been carried out in the region for years, some farmers do not have sufficient information about production and marketing and do not receive support from experts in the field to obtain information,

4. Producers do not follow the developments in modern walnut cultivation and continue traditional cultivation,

5. Failure to get support from experts in the fight against diseases/pests seen in walnut in the region and spraying activities with ancestral methods,

6. The yield per tree in the region is below the average of Türkiye. Producers do not have sufficient knowledge about plant nutrition,

7. Decreases in fruit quality due to improper harvesting time and drying processes,

8. Harvesting is generally done by hitting the tree branches with a pole and the yield losses are high as a result of damage to the shoots,

9. High input costs (diesel, fertilizer and labour prices) from production to marketing,

10. Since only one variety ('Maraş 18') is grown in the region, the same harvest time disrupts the supply and demand balance of the product. Therefore, this situation leads to price differences,

11. Exorbitant price applied to the product by the producer due to the long storage period,

12. Walnut gardens are scattered due to the rugged structure of the region. The low number of orchards,

14. Although walnut cultivation is intensively carried out in the region, producers cannot gather under a single roof of organizations such as unions and cooperatives and therefore cannot form a power union,

15. It can be listed as an inability to provide a price unity due to the intensity of unregistered sales in the region.

5. Conclusion

Although Türkiye is one of the leading countries in world walnut production, walnut production in the domestic market does not meet the need. In other words, there is a walnut production deficit of almost twice as much as the walnuts produced in Türkiye. Unfortunately, a significant part of this production deficit is tried to be closed through imports. In Kahramanmaraş, one of Türkiye's leading walnut-producing provinces, support should be provided to producers and marketers in walnut-producing provinces and districts through both state and private sector enterprises.

Festivals play an important role in the promotion and marketing of walnuts. Especially cultural festivals organized by municipalities are of great importance for the promotion of walnut products. These festivals provide a platform for both local people and external visitors to introduce various uses and flavours of walnuts, to exhibit and sell the products. In addition, the cultural and economic importance of walnuts is emphasized through festivals, thus increasing the marketing and awareness of the product. Therefore, cultural festivals organized by municipalities in cooperation with walnut producers are seen as an important tool to increase the competitiveness of walnuts in the local and national markets. In addition, international participation in these festivals will have an important place in the promotion of this important variety abroad.

As a result; to increase walnut production/market share in Kahramanmaraş Çağlayancerit district and to compete in the market, it will be beneficial to establish cooperatives or producer unions and to improve the existing ones. In addition, it is important to support private sector investments and regional producers by the state. Providing necessary training and information to producers and farmers by experts in their fields from walnut cultivation to marketing will contribute to solving the problems. The number of covered garden facilities should be increased and walnut cultivation should be encouraged. In addition, activities such as advertising and marketing should be given more importance in presenting the produced walnuts to the market and branding should be accelerated.

Author Contributions

The percentages of the authors' contributions are presented below. All authors reviewed and approved the final version of the manuscript.

	Z.A.	A.Ö	M.A
C	30	40	30
D	40	30	30
S	20	40	40
DCP	50	30	20
DAI	40	30	30
L	40	40	20
W	50	30	20
CR	20	40	40
SR	40	30	30
PM	30	40	30
FA	50	30	20

C= concept, D= design, S= supervision, DCP= data collection and/or processing, DAI= data analysis and/or interpretation, L= literature search, W= writing, CR= critical review, SR= submission and revision, PM= project management, FA= funding acquisition.

Conflict of Interest

The authors declared that there is no conflict of interest.

Ethical Consideration

Ethics committee approval was not required for this study because there was no study on animals or humans.

References

Ahmad N, Singh SR, Rashid M, Mir H. 2018. Walnut. Fruit Production, New Delhi, India, pp: 661-672.

Akhmadi H. 2018. Use of information and communication technology (ICT) on agricultural marketing in Indonesia: A brief literature review. 4th International Conference on Food and Agriculture Resources, 11-13 September, Tashkent, Uzbekistan, pp: 283-286.

Anonymous. 2024a. Besin değerleri. URL: https://www.turkalp.org/besin_degerleri.php (accessed date: March 26, 2024).

Anonymous. 2024b. Doğu akdeniz kalkınma ajansı. URL: https://www.dogaka.gov.tr (accessed date: March 27, 2024).

Anonymous. 2024c. Genetiği değiştirilmiş organizmalar. URL: https://www.eeas.europa.eu/delegations/Türkiye/4949/farfi-gitdalar_tr?s=230 (accessed date: March 26, 2024).

Arcan ÜM, Sütyemez M, Bükücü ŞB, Özcan A, Gündeşli MA, Kafkas S, Kafkas NE. 2021. Determination of fatty acid and tocopherol contents in Chandler× Kaplan-86 F1 walnut population. Turk J Agric For, 45(4): 434-453.

Atay MS, Kartal C. 2020. Tarımsal ürün pazarlaması ve tarımsal işlemlerin muhasebeleştirilmesi. SDÜİİBFD, 25(2): 185-201.

Aytekin FZ, Çetinkaya S, Akbay C. 2022. Kahramanmaraş ilinde ceviz üreten işletmelerin analizi. TURKJANS, 9(3): 658-665. https://doi.org/10.30910/turkjans.1104059

Bayazıt S, Sümbül A. 2012. Determination of fruit quality and fatty acid composition of Turkish walnut (*Juglans regia*) cultivars and genotypes grown in subtropical climate of eastern Mediterranean region. IJAB, 14(3): 419-424.

Bou Abdallah I, Baatour O, Mechrgui K, Herchi W, Albouchi A, Chalghoum A, Boukhchina S. 2016. Essential oil composition of walnut tree (*Juglans regia* L.) leaves from Tunisia. J Essent

Oil Res, 28(6): 545-550.

Britton MT, Leslie CH, McGranahan GH, Dandekar AM. 2007. Walnuts. In Pua EC, Davey MR eds. Biotechnology in agriculture and forestry, transgenic crops. SpringerVerlag Berlin, Heidelberg, Germany, pp: 349-370).

Budak Y. 2010. Ceviz yetiştiriciliği. Türkiye Cumhuriyeti Samsun Valiliği İl Tarım Müdürlüğü Çiftçi Eğitimi ve Yayım Şube Müdürlüğü yayınları, Ankara, Türkiye, ss: 142.

Çalış H. 2014. Kahramanmaraş'ta geleneksel el sanatları. Akdeniz'in altın kenti Kahramanmaraş. Kahramanmaraş İl Kültür ve Turizm Müdürlüğü Yayını, Kahramanmaraş, Türkiye, ss: 306

Girma Y, Abebe A. 2019. ICTs and agricultural marketing in Africa: A review. Inform Knowledge Manage, 9(10): 11-17.

Gundlach GT, Wilkie WL. 2009. The american marketing association's new definition of marketing: Perspective and commentary on the 2007 revision. J Public Policy Mark, 28(2): 259-264.

Güvenç İ, Kazankaya A. 2019. Türkiye'de ceviz üretimi, dış ticareti ve rekabet gücü. YYUJAGRSCI, 29(3): 418-424.

Güvenç İ, Purlu G. 2022. Türkiye'nin 2020-2045 döneminde ceviz üretim ve gereksinim projeksiyonu. KSU J Agric Nat, 25(1): 57-65.

Hardesty SD. 2009. The conversion of diamond walnut growers. J Coop, 29: 40-52.

Haskınacı Ş. 2003. Ceviz sektör araştırması. İstanbul Ticaret Odası Yayınları. https://www.ito.org.tr/Dokuman/Sektor/117.pdf (accessed date: March 27, 2024).

Hisarlı A. 1989. Tarım sektörünün ekonomik gelişmeye ürün katkısı. AÜİİBFD, 7(2): 241-248.

Kadakoğlu B, Bayav A, Karlı B. 2022. Türkiye'de ceviz üretim projeksiyonu ve rekabet gücü analizi. Meyvecilik Araş Enstit Müd, 9(1): 8-15.

Kaşka N, Güleryüz M, Kaplankıran M, Kafkas S, Ercişli S, Eşitken A, Aslantaş R, Akçay ME. 2005. Türkiye meyveciliğinde üretim hedefleri. VI. Ziraat Mühendisliği Teknik Kongresi, 3-7 Ocak, Ankara, Türkiye, ss: 519-549.

Ketenci CK. Bayramoğlu Z. 2018. Türkiye'de ceviz üretiminin rekabet analizi. TURKJANS, 5(3): 339-347.

Ketenci KC, Bayramoğlu Z. 2020. Kırşehir ili kaman ilçesinde ceviz yetiştiriciliğinin yatirim analizi ve kârliliğin belirlenmesi üzerine bir araştırma. Ordu Üniv Bilim Tekn Derg, 10(1): 11-22.

Özçağıran R, Ünal A, Özeker E, İsfendiyeroğlu M. 2007. Ilıman iklim meyve türleri: sert kabuklu meyveler (Cilt III). EÜ Ziraat Fakültesi Yayınları No: 566, İzmir, Türkiye, ss: 124.

Özcan A, Sutyemez M, Attar S, Kafkas E, Ergun M. 2020. Fatty acid composition, phenolic compound content and antioxidant activity of unique walnut genotypes with red seed coat. J Food Nutr Res, 59(4).

Özcan A, Sütyemez M. 2019. Cevizde depolama süresinin protein ve yağ kompozisyonuna olan etkisinin belirlenmesi. YYUJ Agri Sci, 29(4): 628-633.

Polat C, Dindaroğlu T. 2014 Ceviz Ağacının (*Juglans regia* L.) Alçak ahşap yüzey oymaciliğinda kullanimi ile bazi ekolojik özelliklerinin irdelenmesi. Atlas Ulus Sos Bilim Derg, 2(3): 87.

Şahin İ. 2005. Sağlıklı beslenmede ceviz. Bahçe, 34(1): 157-162.

Şen SM. 2011. Ceviz. Ankara: ÜÇM yayıncılık, Ankara, Türkiye, ss: 142.

Şimşek M, Gülsoy E. 2016. The important in terms of human health of the walnut and the fatty acids and some studies on this subject. J Inst Sci Tech, 6(4): 9-15.

Sütyemez M, Bükücü ŞB, Özcan A. 2022. Pomological and phenological description of the new 'Bahri Koz'cultivar of walnut (*Juglans regia* L.) and its nutritional value. J Nuts, 13(2): 131-139.

Sütyemez M, Eti S. 2001. Kahramanmaraş bölgesinde selekte edilen ümitvar ceviz tiplerinin genel pomolojik özellikleri. Türkiye I. Ulusal Ceviz Sempozyumu, 16-19 Kasım, Denizli, Türkiye, 77(93): 5-8.

Sütyemez M. 2000. Kahramanmaraş'ta ceviz yetiştiriciliği. KSÜ Fen ve Müh Derg, 3(2): 69-74.

Sütyemez M. 2016. New walnut cultivars: Maras 18, Sutyemez 1, and Kaman 1. HortSci, 51(10): 1301–1303.

The State of Food Security and Nutrition in the World (FAO) 2024. Food and Agriculture Organization of the United Nations, World Food Summit, Rome (Food & Agricultural Organization URL: https://www.fao.org/home/en (accessed date: March 29, 2024).

Turkish Statistical Institute (TURKSTAT). 2024. Tarım istatistikleri URL: https://biruni.tuik.gov.tr/medas/?kn=92&locale=tr (accessed date: March 03, 2024).

Vural H. 2021. Ceviz ekonomisi ve pazarlaması. XVI. IBANESS İktisat, İşletme ve Yönetim Bilimleri Kongresi, 25-27 Mayıs, İstanbul, Türkiye, ss: 311-319.

Yıldız E, Sümbül A. 2019. Uşak ilinden seçilmiş ceviz genotiplerinde meyvelerin mineral madde içerikleri. ADÜ Zir Derg, 16(2): 179-183.

Yücer MM. 2013. Ceviz. İstanbul: Hasad yayıncılık, İstanbul, Türkiye, ss: 23.

Black Sea Journal of Agriculture
doi: 10.47115/bsagriculture.1627058

Open Access Journal
e-ISSN: 2618 – 6578

Research Article
Volume 8 - Issue 2 : 205-216 / March 2025

THE EFFECT OF INVESTMENTS, MECHANIZATION AND FERTILIZER USE ON AGRICULTURAL GROWTH IN TÜRKİYE'S AGRICULTURAL SECTOR: AN ECONOMETRIC ANALYSIS

Gülferah ERTÜRKMEN[1]*

[1]Kahramanmaraş Sütçü İmam University, Göksun School of Applied Sciences, Department of Finance and Banking, 46000, Kahramanmaraş, Türkiye

Abstract: This research comprehensively examines the economic factors affecting agricultural growth in Türkiye between 1998 and 2022. The agricultural sector has a strategic importance for economic growth and rural development. In the study, variables affecting agricultural growth such as fixed capital investments, use of agricultural machinery and fertilization are considered and the effects of these factors are analyzed by econometric methods. The data set used in the study is based on annual data covering the years 1998-2022. The stationarity levels of the data are analyzed by Augmented Dickey-Fuller (ADF), Phillips-Perron (PP) and Kwiatkowski-Phillips-Schmidt-Shin (KPSS) unit root tests. VAR model is used to analyze the dynamic relationships of time series, Toda-Yamamoto causality test is used to determine the direction of the effects, impulse-response functions and period decomposition methods are used to evaluate the magnitude and duration of the effects. Diagnostic tests such as normality, autocorrelation and variance tests were used to test the validity of the model. The results of the research show that the impact of fixed capital investments on agricultural growth is significant and that private sector investments have become more determinant in recent years, although public investments were effective in the early years. Modern agricultural practices such as the use of agricultural machinery and nitrogen fertilizers have been found to increase productivity in the short run, but have limited effects in the long run. Despite the declining share of agriculture in GDP, the sector remains critical for economic growth, rural employment and food security.

Keywords: Economic growth, Agricultural growth, Economic determinants

***Corresponding author:** Kahramanmaraş Sütçü İmam University, Göksun School of Applied Sciences, Department of Finance and Banking, 46000, Kahramanmaraş, Türkiye
E mail: gbozkaya@ksu.edu.tr (G. ERTÜRKMEN)
Gülferah ERTÜRKMEN https://orcid.org/0000-0003-2239-0241

Received: January 25, 2025
Accepted: February 25, 2025
Published: March 15, 2025

Cite as: Ertürkmen G. 2025. The effect of investments, mechanization and fertilizer use on agricultural growth in Türkiye's agricultural sector: an econometric analysis. BSJ Agri, 8(2): 205-216.

1. Introduction

The agricultural sector is strategically important for economic development and growth as well as meeting humanity's basic nutritional needs. Factors such as the growing world population, climate change, rapid resource depletion and global political tensions have further increased the importance of agriculture both locally and globally (Bağcı, 2022). In this context, the agricultural sector not only provides food security, but also makes significant contributions to macroeconomic objectives such as economic growth, job creation and poverty reduction. Especially in developing countries, agriculture is often one of the largest sources of employment and the livelihood of rural populations (Benfica et al., 2019).

Technological advances make it possible to produce more with fewer resources by optimizing agricultural production processes. All agricultural activities such as irrigation, fertilization, harvesting and storage benefit from advanced technology (Kılıçarslan and Dinç, 2007). However, in developing countries such as Türkiye, the inadequacy of agricultural equipment and the lack of technological infrastructure prevent the production level from reaching the desired level (Taban and Kar, 2016). Therefore, the integration of technological innovations in the agricultural sector is of great importance. Technology not only increases production efficiency, but also helps to raise the welfare level and living standards of countries.

Investments in the agricultural sector directly affect not only agricultural production but also economic growth. Fixed capital investments contribute to economic growth by increasing agricultural productivity (Roy and Pal, 2002). Today, fertilizers, which constitute approximately 15-20% of agricultural production costs, are considered as an indispensable element in terms of increasing agricultural productivity. Correct and conscious fertilization can increase yields in crop production by 50-75%, and this increase can be up to 100% in some crops. Various studies on ways to increase productivity in agricultural production have shown that fertilizer use has a significant impact on agricultural yield. However, fertilization is not the only way to increase agricultural productivity (Tıraş, 2024). Mechanization in agriculture is also one of the important factors affecting productivity. Mechanization means the replacement of human and animal power by mechanical energy in agricultural activities. The most important symbol of this process is the tractor. Since the 1930s, there has been a great increase in the use of tractors worldwide. Especially between 1930 and 1953, the number of tractors in the world quintupled (Anker, 1956). This development was an important step that increased productivity in the agricultural sector.

The agricultural sector in Türkiye has a great potential thanks to its geographical location and climate diversity. However, problems such as the fragmented structure of agricultural lands, lack of technological equipment and ineffective use of agricultural supports prevent the sector from reaching its full potential (Tan et al., 2015). Moreover, the downward trend in employment due to mechanization and industrialization in agriculture negatively affects the sector's capacity to attract labor force. Despite this, the agricultural sector in Türkiye still maintains its importance and provides about 20% of employment (Gülçubuk, 2005). Considering the contributions of the agricultural sector to nutrition, employment, industry, national income and ecological balance, it stands out as a sector that cannot be ignored (Yıldız and Oğuzhan, 2007).

Considering the impact of agricultural growth on economic growth, it is of great importance to reveal the relationship between agricultural subsidies, the share of agriculture in GDP, public and private fixed capital investments in the sector and the number of agricultural employment. In the literature, there are many studies in which the positive effect of fixed capital investments on agricultural growth is determined (Roy and Pal, 2002; Fan et al., 2008). In addition, agricultural loans and subsidies are also reported to stimulate agricultural growth (Şaşmaz and Özel, 2019). However, the decline in the population employed in agriculture is seen as a consequence of technological advances, which has a negative impact on agricultural growth (Terin et al. 2013).

The aim of this research is to identify the economic factors affecting agricultural growth in Türkiye between 1998 and 2022 and to analyze the effects of these factors using econometric methods. In the study, the effects of variables such as fixed capital investments, agricultural machinery use and fertilization on agricultural growth are examined in detail. In the analysis process, time series methods are used to test the relationships between variables, Toda-Yamamoto causality analysis, impulse-response functions and period decomposition methods are applied. One of the most important features that distinguishes this research from similar studies in the literature is that it comparatively analyzes the changes in public and private investments in the agricultural sector over time and reveals the short and long term effects of these investments on agricultural growth. Moreover, in order to ensure the reliability of the model, various diagnostic tests were applied to test the validity of the analysis.

1.2. Literature

The agricultural sector constitutes one of the basic building blocks of the economy in terms of production activities and the trade of the values obtained from this production. This sector, which has a wide scope, has an important place at the macroeconomic level. In this research, the factors affecting agricultural growth and the effects of these factors on agricultural growth are discussed. A review of the literature reveals that there are limited studies in which factors such as fixed capital investments, agricultural subsidies and agricultural employment, which have an impact on economic growth, are considered together. However, there are many co-integration studies examining the relationship between economic growth and agricultural subsidies or economic growth and capital investments. In this context, studies conducted both in Türkiye and in different countries have been included in the literature. Summaries of these studies are presented below:

The importance of agricultural credits on agricultural production has been emphasized in many academic studies. Das et al. (2009) evaluated the effects of agricultural loans on agricultural production, while Rahman (2011) and Ammani (2012) similarly addressed the critical role of these loans in agricultural production. More recently, Duramaz and Taş (2018) and Kadanalı and Kaya (2020) examined this relationship in detail and found that agricultural loans are an important tool to increase agricultural production. These studies clearly demonstrate the role of agricultural credits on the continuity and growth of agricultural activities.

The impact of agricultural credits on economic growth and the contribution of economic growth to agricultural credits have been analyzed from different perspectives. Yıldız and Oğuzhan (2007), Anthony (2010), Kaya et al. (2012), Ekwere and Edem (2014), Çevik and Zeren (2014) and Apaydın (2018) have shown the positive effects of agricultural credits on economic growth. In addition, Akram and Hussain (2008) argue that economic growth in Pakistan supports agricultural production by increasing the demand for agricultural loans. Olagunju and Adeyemo (2007) show that economic growth in Nigeria accelerates rural development by increasing agricultural sector loans. In Türkiye, Çetin and Ecevit (2015) find that economic growth facilitates access to agricultural loans, while Demir and Özcan (2019) find that economic growth has long-term positive effects on agricultural loans. Moreover, Önder (2023) argues that the relationship between agricultural loans and economic growth is long-run and positive, but these loans are not the cause of economic growth.

Studies examining the effects of agricultural credits on agricultural growth reveal important results in this field. Iganiga and Unemhilin (2011) and Akmal et al., (2012) emphasized the positive effects of these credits on agricultural growth, and Cömertler Şimşir (2012) reached similar findings. In more recent studies, Yalçınkaya (2018), Koç et al. (2019) and Tuan et al.,

(2020) have analyzed the contribution of agricultural loans to agricultural growth in detail. However, the increase in agricultural credit encourages the use of agricultural inputs but has a weak impact on agricultural GDP. In the Turkish context, there is a positive long-term relationship between agricultural credit and agricultural growth using data from 2005-2021.

The effects of agricultural R&D expenditures have attracted attention in Türkiye-specific studies. Subaşı and Ören (2013) found that total factor productivity increased by 0.51% annually due to technical efficiency and technological change. Özaydın and Çelik (2019) emphasized the positive impact of R&D expenditures on agricultural growth worldwide and predicted that this increase will continue until 2023. Özen et al. (2024) examined the relationship between carbon emissions (CO_2) and human development (HDI), urbanization (PU), industrialization (SAN) and agricultural development (AGR) in Türkiye between 1990-2020. According to the results of Toda-Yamamoto causality test, CO_2 emissions are affected by HDI and AGR indicators, but not by PU and SAN indicators. Ülger (2025) analyzed the impact of agriculture, industry and economic growth on carbon emissions in E-7 countries in the period 1992-2020. As a result of the analysis with the panel ARDL method, it is determined that agricultural activities reduce carbon emissions in the long run, while industry and economic growth increase emissions. In the short run, economic growth increases emissions, while the effect of agriculture and industry is not significant.

Some studies have focused on the effects of public investments and incentives. Public fixed capital investments do not have a significant effect on economic growth. Şaşmaz and Özel (2019) find that fiscal incentives provided to the agricultural sector are ineffective in the long run, but economic growth has a positive effect on the agricultural sector. Köse and Meral (2021), on the other hand, find no link between economic growth and agricultural subsidies.

The effects of economic growth on the agricultural sector have also been analyzed with cross-sectoral comparisons. Kopuk and Meçik (2020) found that there is a unidirectional causality relationship from the agricultural sector to economic growth in Türkiye. Canbay and Kırca (2020) found that agriculture has a positive effect on growth, while growth has a negative effect on agriculture. Okine and Özel (2018)'s research on Ghana, found that an increase in agricultural production increases GDP growth. Finally, Merdan (2023) analyzed the economic factors affecting agricultural growth in the 2000-2022 period and emphasized the positive effects of agricultural subsidies and fixed capital investments and the negative effects of agricultural employment. In general, it is understood that investments in the agricultural sector and agricultural R&D activities stimulate economic growth, but this effect is sometimes limited or depends on sector-specific dynamics.

2. Materials and Methods

In this section of the study, the variables used in the research, the data set, econometric methods and the results of the analysis are presented.

2.1. Data Set Used in the Study

This research utilizes annual data for the period 1998-2022 in Türkiye. In all variables used in the analysis, year intervals that ensure data integrity are used. In line with the objective of the study, in order to investigate the factors affecting agricultural growth, agricultural GDP was used as the dependent variable and investment in agriculture sector (public and private) within fixed capital investments, share of agriculture in GDP, agricultural machinery per agricultural land and nitrogen fertilizer use were used as independent variables. Before starting the data analysis and modeling process, logarithmic transformation was applied to the data to normalize the data, minimize the effect of extreme outliers and linearize exponential relationships. Table 1 presents the variables and data sources.

Table 1. Variables and Data Sources

Variables	Data Sources
Agricultural GDP (%) (AGDP)	Türkiye Strategy and Budget Presidency
Investment in the Agricultural Sector within Fixed Capital Investments (Public) (IACP)	Türkiye Strategy and Budget Presidency
Investment in the Agricultural Sector within Fixed Capital Investments (Private) (IACPR)	Türkiye Strategy and Budget Presidency
Agriculture Share in GDP (ASG)	Türkiye Strategy and Budget Presidency
Agricultural Machinery Per Agricultural Land (AML)	Türkiye Strategy and Budget Presidency
Nitrogen Fertilizer Use (NFU)	Türkiye Strategy and Budget Presidency

To measure the stationarity level of the data, Augmented Dickey-Fuller (ADF), Phillips-Perron (PP) and Kwiatkowski-Phillips-Schmidt-Shin (KPSS) tests were used to determine whether the statistical properties of the time series changed over time. Various diagnostic tests were applied to ensure the reliability and accuracy of the model. In this context, the inverse roots of the AR characteristic polynomial are used to examine whether the characteristic roots are within the unit circle, the Jarque-Bera Normality test is applied to determine the normality assumption of the model, the Autocorrelation LM test is applied to determine the presence of autocorrelation, and the White Homogeneity/Heterogeneity of Variance test is applied to examine the heteroskedasticity problem.

2.2. Unit Root Test

Series with unit roots are non-stationary series and are affected by exogenous shocks. Series without unit roots are stationary and insensitive to exogenous shocks. This implies that the main logic of unit root tests is to test whether incoming shocks have a temporary or permanent effect on the series (Nelson and Plosser, 1982; Glynn, et al., 2007).

Three methods are generally used to determine whether a time series is stationary or not. These methods are time path graph method, correlagram method and unit root test method (Gujarati, 2011). Before conducting the unit root test, the variables were examined whether they contain a trend or not, and the variables containing a trend were identified and de-trended. These variables are; TBDM, TGS, AGK and TGSP. Table 2 presents the results of ADF, PP and KPSS unit root tests.

Table 2. ADF and PP unit root test results

Level	Variables	ADF	PP
		Intercept (Fixed)	Intercept (Fixed)
I(0)	DEAGDPF	-1.580332 [0.4768]	-1.830806 [0.3574]
	DEASGF	-4.101375*** [0.0043]	-4.109657*** [0.0043]
	DEAMLF	0.307267 [0.9737]	-0.453837 [0.8841]
	DENFUF	-3.081500** [0.0429]	-4.661064*** [0.0015]
	IACP	-0.946346 [0.7551]	-0.973965 [0.7456]
	IACPR	-0.387671 [0.8964]	-0.407460 [0.8929]
I(1)	ΔDEAGDPF	-1.829248 [0.3578]	-1.648278 [0.4430]
	ΔDEAMLF	-2.986493 [0.0512]	-2.924642 [0.0579]
	ΔIACP	-3.369588** [0.0243]	-2.539329 [0.1198]
	ΔIACPR	-4.495746*** [0.0018]	-4.491122*** [0.0019]
I(2)	ΔΔDEAGDPF	-5.445986* [0.0002]	-5.445986* [0.0002]
	ΔΔDEAMLF	-9.027249*** [0.0001]	-9.131013*** [0.0001]
	ΔΔIACP	-5.294303” [0.0003]	-5.323201*** [0.0003]

Note= ***, ** and * denote significance at 1%, 5% and 10% significance levels, respectively. Δ= represents taking the difference.

Before applying the unit root tests, it is checked whether the variables are trended or not. Since all variables included in the analysis are trended except for the AGDP variable, the stationarity of the variables was evaluated based on the fixed and trended column in the unit root test. In Table 2, it is seen that the variables except NFU and AGDP are non-stationary according to ADF, PP and KPSS test results (P<0.05). When the first differences of the variables are taken as I(1), it is found that only the SCCT variable is stationary. The variables IACP, AML and AGDP are I(2) stationary at the second difference (P<0.05).

3.3. Diagnostic Test Results

The diagnostic tests in the analyses are used to check whether the VAR (1) model, which is estimated after determining the lag length of the series, is stationary and whether there is autocorrelation and heteroscedasticity problem in the model. In this context, the diagnostic test results obtained in the analyses are reported and given below, respectively.

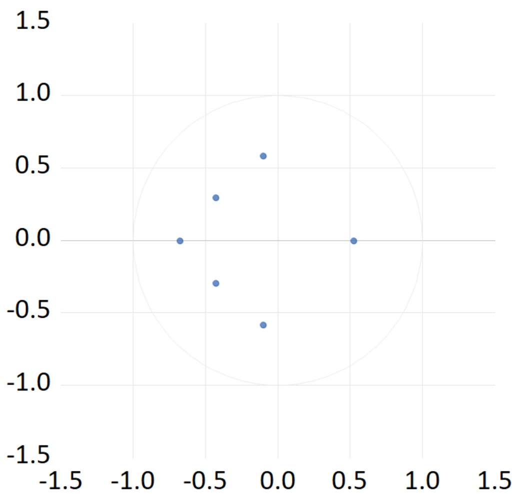

Figure 1. Inverse roots of the ar characteristic polynomial.

The circle graph in Figure 1 shows that the characteristic roots are within the unit circle, hence they are smaller than 1 in absolute degree and as a result, the stability condition is satisfied. The fact that all of the characteristic roots are within the unit circle indicates that the estimated VAR (1) model is stationary. This means that the stability condition is met in the VAR (1) model. Table 3 presents the results of normality, autocorrelation lm and white variance test.

Table 3. Normality, autocorrelation LM and White variance test results

Component	Skewness χ^2 value	df (degrees of freedom)	P value
Unified	4.104	6	0.663
Component	Kurtosis χ^2 value	df (degrees of freedom)	P value
Unified	40.356	6	0.999
Component	Jarque-Bera	df (degrees of freedom)	P value
Unified	4.460	12	0.974
Lag	LRE* stat	df (degrees of freedom)	P value
1	51.881	(36,20.3)	0.102
Lag	χ^2 value	df (degrees of freedom)	P value
1	264.000	252	0.289

According to the results in Table 3, since the p-values of skewness, kurtosis and Jarque-Bera tests are greater than 0.05 significance level, it is seen that the normality assumption is met. According to the results of the Autocorrelation LM Test, since the p-value is greater than 0.05, it is determined that there is no autocorrelation, that is, there is no dependence relationship between the data. Finally, according to the results of the White Variance test, since the p-value is greater than 0.05, it is concluded that there is no varying variance problem. Overall, these results indicate that the model has a strong basis in terms of assumptions.

3.4. Impact-Response Functions

Impulse-response functions reveal the effects of a one standard deviation shock to a random error term on both the current and future values of endogenous variables. These functions play an important role in detecting dynamic and symmetric interactions between the variables analyzed by VAR method. While the variance decomposition method is used to determine which variable is the most influential variable on macroeconomic indicators, whether this variable can be used as a policy instrument is determined with the help of impulse-response functions (Sarı, 2008).

Shocks to economic variables in an economy are generally analyzed in two different categories. The first one is permanent and its effects persist in the long run. In other words, such shocks can significantly affect not only the period in which they occur but also future periods. One of the best examples of this situation is technology-based shocks. Transitory shocks, which fall into the second category, have a strong impact as of the moment of their emergence, but lose their permanent characteristics with the disappearance of this effect in a short time (Aktaş, 2010). Figure 2 shows the results of impulse-response functions applied to the VAR (1) estimation model.

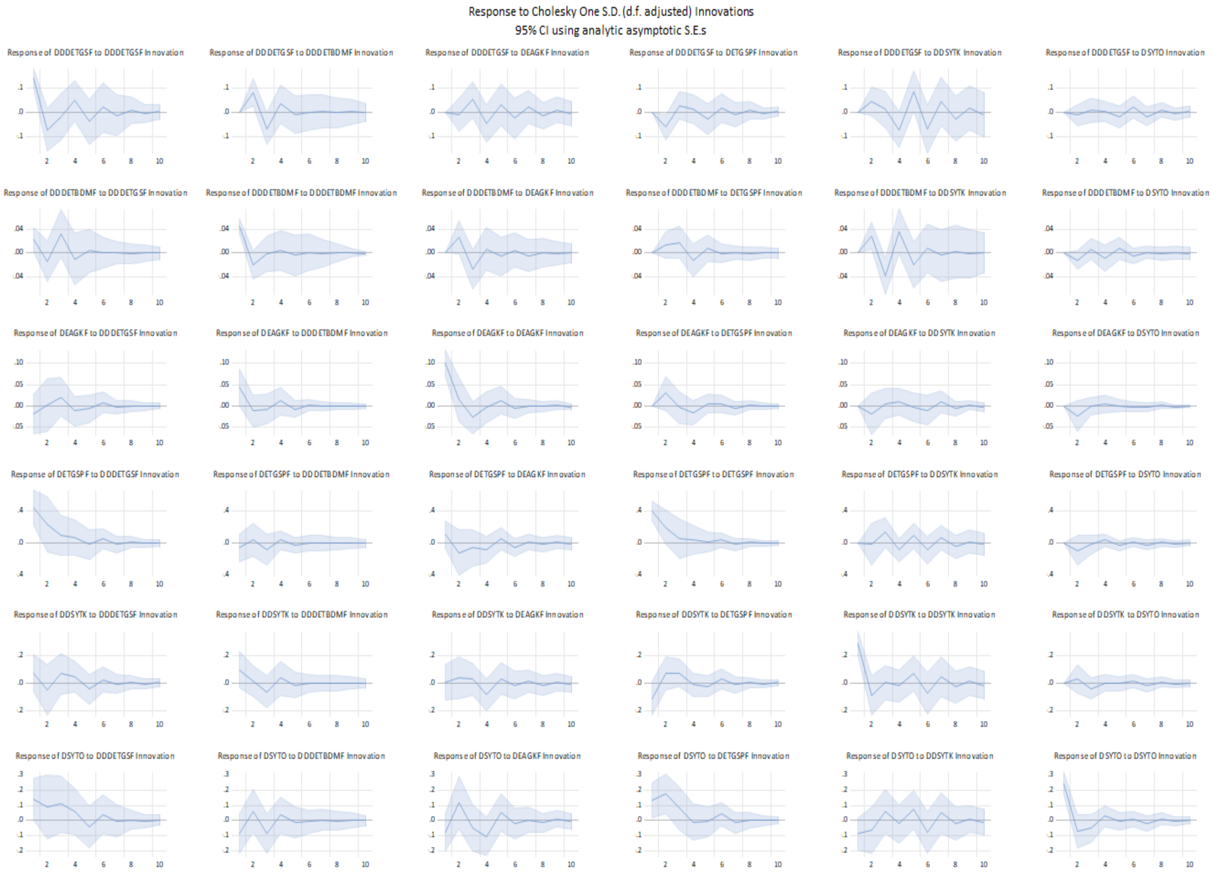

Figure 2. Impulse-response test results

The graphs in Figure 2 represent impulse-response functions showing the effects of Cholesky unit standard deviation shocks on variables and how these effects diminish over time. Some graphs show that the effect of agricultural machinery per agricultural land on other variables is short-lived and small-scale. The effect usually starts positive and rapidly approaches zero. For example, the effect of agricultural machinery per agricultural land on the agricultural GDP variable appears to be significant and positive in the first few periods. However, this effect weakens over time. The response of agricultural machinery per agricultural land to shocks from other variables is generally weak and short-term. This may indicate that agricultural machinery shows a rapid adaptation in the short run. Regarding the effect of agricultural GDP on other variables, the effect of the shock for nitrogen fertilizer use is generally weak in the short run and the confidence interval is wide. This implies that agricultural GDP does not have a significant impact on fertilizer use. The effects of private and public fixed capital investments on agricultural sector investment variables decline over time and approach zero. When the response of agricultural GDP is analyzed, it is found that the responses to shocks from other variables are more long-term. In particular, shocks from investments can have an impact on agricultural GDP for several periods. When the effect of nitrogen fertilizer use on other variables is examined, it is seen that its effect on agricultural machinery and investments is generally minimal and short-term. The response of nitrogen fertilizer use to shocks from other variables, on the other hand, is initially abrupt but soon stabilizes. The effect of agricultural GDP share on other variables is generally not significant. Since confidence intervals are wide around the zero line, the effects may not be statistically significant. The response of the share of agricultural GDP to shocks from other variables generally returns to zero in a short time. Finally, when the effects of private and public fixed capital investments on agricultural investment variables are analyzed, the effects of public and private investments on agricultural GDP and fertilizer use generally start positive but converge to zero over time. This suggests that the effects of investments on agriculture may be temporary. Regarding the response of investments, it is found that shocks, especially from variables such as agricultural GDP, can have short-term and sometimes volatile effects on investments. In general, short-term effects suggest that many variables respond quickly to shocks, and that the effects often weaken within a few periods. In terms of statistical significance, shock effects are not significant when blue confidence intervals are wide. Finally, policy implications suggest that the effects of variables such as investments and agricultural machinery on agricultural GDP should be examined in more detail and supported by long-term strategies.

3.5. Periodic Decomposition

In their study, Burbidge and Harrison (1985) transformed the residuals of the VAR model into structural residuals, and as a result of this transformation, each variable in the system was decomposed for each T time point by considering it as the sum of its own structural shocks as well as the structural shocks of other variables throughout the sample period.

While Impulse Response Analysis is used to understand the dynamic structure of the relationships between variables, the periodic decomposition test is used to understand the sources of past fluctuations. Figure 3 shows the periodic decomposition test results.

The periodic decomposition graphs in Figure 3 are evaluated in 3 periods: the first, middle and last year. The first year represents around 2000 (the period when the data starts), the middle year represents around 2010 (the middle years) and the last year represents 2020 (the period when the data ends). When the graphs are examined for the variable of agricultural machinery per agricultural land, the fluctuations in agricultural machinery in the first years are generally explained by shocks from public and private investments. In these years, the effect of investments significantly affected the fluctuation in the use of agricultural machinery. In the middle years, the effects from agricultural growth created a positive contribution to agricultural machinery. The effect of fertilizer use shocks becomes less pronounced in this period. In recent years, public investments have increased their effect and the blue bars have started to grow as seen in the graphs. This situation indicates the effect of public policies on agricultural machinery in recent years.

For the agricultural GDP variable, the change in agricultural GDP in the early years is explained mostly by shocks from public investments and agricultural machinery. The middle years indicate that the effect of private investments has increased and this situation has played a significant role on agricultural growth. In recent years, the effect of shocks from public investments and agricultural machinery has decreased, and private investments and fertilizer use have become more pronounced. For the nitrogen fertilizer use variable, the shocks from agricultural GDP and public investments in the early years have had dominant effects on fertilizer use. In the middle years, it has been determined that the source of changes in fertilizer use comes mostly from agricultural machinery and private investments. In recent years, the size of the blue bars has decreased and fluctuations in fertilizer use have become more limited. For the share in agricultural GDP variable, the early years have increased with effects from public investments and agricultural machinery. In the middle years, the effects from private investments have increased, but the overall contributions are limited. In recent years, the effect of public investments has weakened and the effects on agricultural share have become more balanced. If we look at the public investment variable, it had an impact on agricultural GDP and fertilizer use in the early years.

The effect of private investments is limited in this period. In the middle years, the effect of private investments increased and its role on agricultural growth became apparent. In recent years, public and private investments have created a balanced effect, especially the effects on agricultural machinery are remarkable. If the inferences on a yearly basis are evaluated in general terms, it is seen that the effects of public investments and agricultural machinery were dominant in the early years. In addition, agricultural growth was more affected by public policies. In the middle years, the effect of private investments began to become apparent. Agricultural machinery and fertilizer use contribute more to the fluctuations in agricultural GDP. In recent years, the effect between public and private investments has been balanced, especially the effects on agricultural machinery have increased. Fertilizer use has started to lose its effect on agricultural growth.

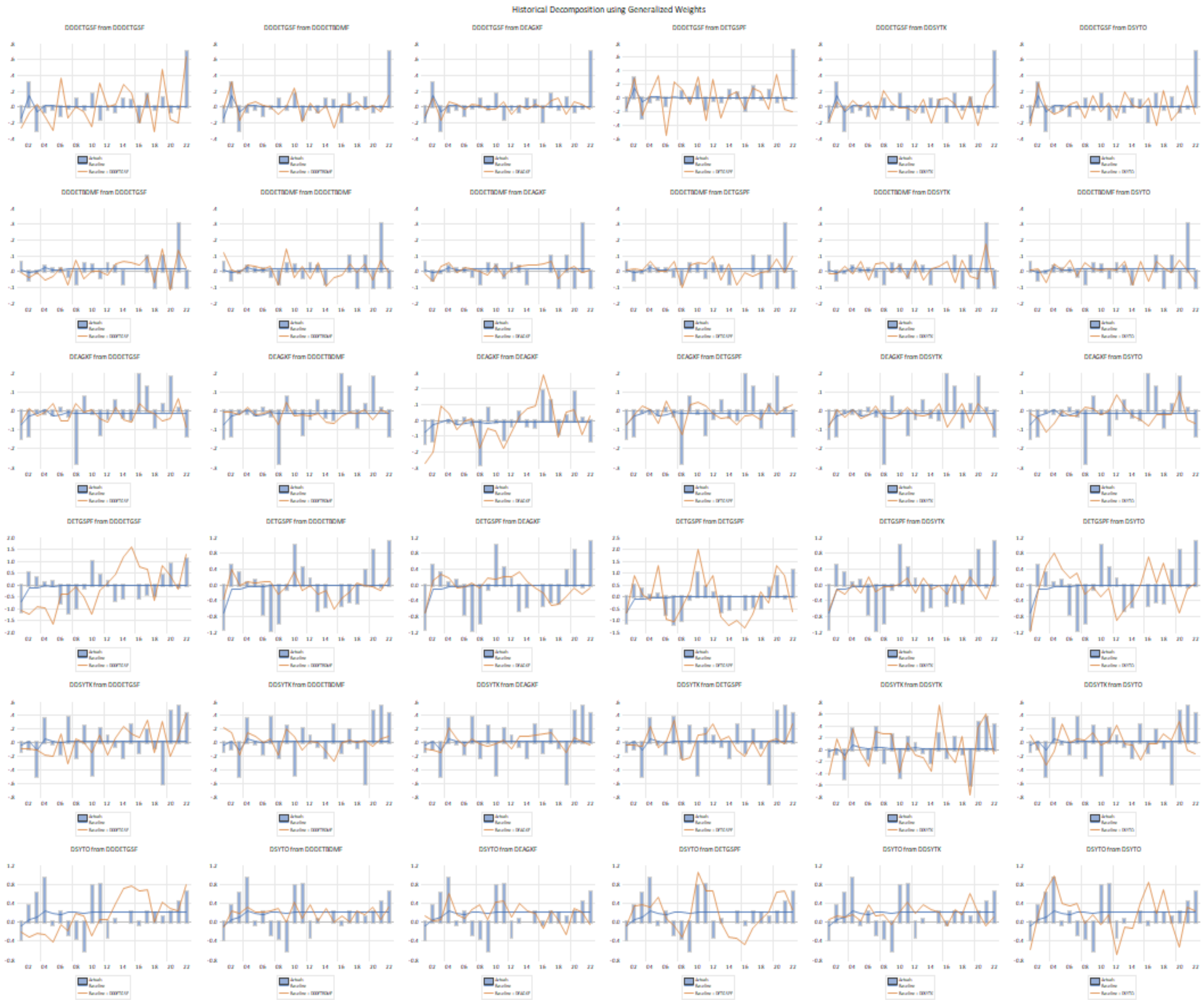

Figure 3. Periodic decomposition test results

3.6. Toda-Yamamoto Causality Test

The Toda-Yamamoto causality test was developed by Toda and Yamamoto in 1995 to investigate the existence and direction of the causality relationship between variables. This method is applied to variables through a VAR model with increased lag. The Toda-Yamamoto causality test has two important advantages over other causality tests. Firstly, only the stationarity test is used to determine the maximum lag length. Second, this test does not require a precondition such as the presence of a cointegration relationship between variables. In the first step of the test, the level at which the variables are stationary is determined and this value is called "dmax". After dmax is determined, the appropriate lag length for the variables is determined and this value is indicated by "k". In the third step, the VAR model with increased lag is estimated by combining the determined dmax and k values. In the last step, the Toda-Yamamoto causality test is applied to the variables through this model (Mert and Çağlar, 2019; Toda and Yamamoto, 1995). The Toda-Yamamoto causality models for the variables used in the study are shown in the equations (1-6) below. Table 4 shows the results of the Toda-Yamamoto causality test.

$$dddeagdpf_t = \mu + \sum_{i=1}^{k+d_{max}} \alpha_1 dddeagdpf_{t-i} + \sum_{i=1}^{k+d_{max}} \alpha_2 dddeamlf_{t-i} + \sum_{i=1}^{k+d_{max}} \alpha_3 denfuf_{t-i} + \sum_{i=1}^{k+d_{max}} \alpha_4 deasgf_{t-i} + \sum_{i=1}^{k+d_{max}} \alpha_5 ddiacp_{t-i} + \sum_{i=1}^{k+d_{max}} \alpha_6 diacpr_{t-i} + \varepsilon_t \quad (1)$$

$$dddeamlf_t = \mu + \sum_{i=1}^{k+d_{max}} \beta_1 dddeamlf_{t-i} + \sum_{i=1}^{k+d_{max}} \beta_2 dddeagdpf_{t-i} + \sum_{i=1}^{k+d_{max}} \beta_3 denfuf_{t-i} + \sum_{i=1}^{k+d_{max}} \beta_4 deasgf_{t-i} + \sum_{i=1}^{k+d_{max}} \beta_5 ddiacp_{t-i} + \sum_{i=1}^{k+d_{max}} \beta_6 diacpr_{t-i} + \varepsilon_t \quad (2)$$

$$denfuf_t = \mu + \sum_{i=1}^{k+d_{max}} \lambda_1 denfuf_{t-i} + \sum_{i=1}^{k+d_{max}} \lambda_2 dddeagdpf_{t-i} + \sum_{i=1}^{k+d_{max}} \lambda_3 dddeamlf_{t-i} + \sum_{i=1}^{k+d_{max}} \lambda_4 deasgf_{t-i} + \sum_{i=1}^{k+d_{max}} \lambda_5 ddiacp_{t-i} + \sum_{i=1}^{k+d_{max}} \lambda_6 diacpr_{t-i} + \varepsilon_t \quad (3)$$

$$deasgf_t = \mu + \sum_{i=1}^{k+d_{max}} \Pi_1 deasgf_{t-i} + \sum_{i=1}^{k+d_{max}} \Pi_2 dddeagdpf_{t-i} + \sum_{i=1}^{k+d_{max}} \Pi_3 dddeamlf_{t-i} + \sum_{i=1}^{k+d_{max}} \Pi_4 denfuf_{t-i} + \sum_{i=1}^{k+d_{max}} \Pi_5 ddiacp_{t-i} + \sum_{i=1}^{k+d_{max}} \Pi_6 diacpr_{t-i} + \varepsilon_t \quad (4)$$

$$diacp_t = \mu + \sum_{i=1}^{k+d_{max}} \phi_1 diacp_{t-i} + \sum_{i=1}^{k+d_{max}} \phi_2 dddeagdpf_{t-i} + \sum_{i=1}^{k+d_{max}} \phi_3 dddeamlf_{t-i} + \sum_{i=1}^{k+d_{max}} \phi_4 denfuf_{t-i} + \sum_{i=1}^{k+d_{max}} \phi_5 deasgf_{t-i} + \sum_{i=1}^{k+d_{max}} \phi_6 diacpr_{t-i} + \varepsilon_t \quad (5)$$

$$diacpr_t = \mu + \sum_{i=1}^{k+d_{max}} £_1 diacpr_{t-i} + \sum_{i=1}^{k+d_{max}} £_2 dddeagdpf_{t-i} + \sum_{i=1}^{k+d_{max}} £_3 dddeamlf_{t-i} + \sum_{i=1}^{k+d_{max}} £_4 denfuf_{t-i} + \sum_{i=1}^{k+d_{max}} £_5 deasgf_{t-i} + \sum_{i=1}^{k+d_{max}} £_6 ddiacp_{t-i} + \varepsilon_t \quad (6)$$

Table 4. Toda-Yamamoto causality test results

Independent Variables	k+d_{max}	χ^2 value	*P* value	Hypotheses	Result
Model 1				**Dependent Variable: dddeagdpf**	
dddeamlf	2	1.648	0.199	H_0: Accept	dddetbdmf ⇏ dddetgsf
denfuf	2	0.076	0.783	H_0: Accept	deagkf ⇏ dddetgsf
deasgf	2	0.030	0.862	H_0: Accept	detgspf ⇏ dddetgsf
ddiacp	2	1.775	0.183	H_0: Accept	ddsytk ⇏ dddetgsf
diacpr	2	0.384	0.535	H_0: Accept	dsyto ⇏ dddetgsf
All	2	7.933	0.160	H_0: Accept	All ⇏ dddetgsf
Model 2				**Dependent Variable: dddeamlf**	
dddeagdpf	2	3.476	0.062	H_0: Accept	dddetgsf ⇏ dddetbdmf
denfuf	2	0.137	0.711	H_0:Accept	deagkf ⇏ dddetbdmf
deasgf	2	9.231	0.002	H_0: Rejection	detgspf ⇒ dddetbdmf
ddiacp	2	6.083	0.014	H_0: Rejection	ddsytk ⇒ dddetbdmf
diacpr	2	2.660	0.103	H_0: Accept	dsyto ⇏ dddetbdmf
All	2	23.603	0.001	H_0: Rejection	All ⇒ dddetbdmf
Model 3				**Dependent Variable: denfuf**	
dddeagdpf	2	2.336	0.126	H_0: Accept	dddetgsf ⇏ deagkf
dddeamlf	2	4.001	0.046	H_0: Rejection	dddetbdmf ⇒ deagkf
deasgf	2	0.506	0.477	H_0: Accept	detgspf ⇏ deagkf
ddiacp	2	0.013	0.910	H_0: Accept	ddsytk ⇏ deagkf
diacpr	2	0.562	0.454	H_0: Accept	dsyto ⇏ deagkf
All	2	8.308	0.140	H_0: Accept	All ⇏ deagkf
Model 4				**Dependent Variable: deasgf**	
dddeagdpf	2	0.874	0.350	H_0: Accept	dddetgsf ⇏ detgspf
dddeamlf	2	2.746	0.098	H_0: Accept	dddetbdmf ⇏ detgspf
denfuf	2	2.165	0.141	H_0: Accept	deagkf ⇏ detgspf
ddiacp	2	0.003	0.955	H_0: Accept	ddsytk ⇏ detgspf
diacpr	2	0.123	0.726	H_0: Accept	dsyto ⇏ detgspf
All	2	4.022	0.546	H_0: Accept	All ⇏ detgspf
Model 5				**Dependent Variable: diacp**	
dddeagdpf	2	0.056	0.813	H_0: Accept	dddetgsf ⇏ dsytk
dddeamlf	2	4.508	0.034	H_0: Rejection	dddetbdmf ⇒ dsytk
denfuf	2	0.111	0.739	H_0: Accept	deagkf ⇏ dsytk
deasgf	2	0.480	0.488	H_0: Accept	detgspf ⇏ dsytk
diacpr	2	1.815	0.178	H_0: Accept	dsyto ⇏ dsytk
All	2	6.265	0.281	H_0: Accept	All ⇏ dsytk
Model 6				**Dependent Variable: diacpr**	
Independent Variables	k+d_{max}	χ^2 value	*P* value	Hipotezler	Result
dddeagdpf	2	2.784	0.095	H_0: Accept	dddetgsf ⇏ dsyto
dddeamlf	2	4.649	0.031	H_0: Rejection	deagkf ⇏ dsyto
denfuf	2	0.001	0.976	H_0: Accept	detgspf ⇒ dsyto
deasgf	2	5.899	0.015	H_0: Rejection	ddsytk ⇒ dsyto
ddiacp	2	0.037	0.846	H_0: Accept	dsyto ⇏ dsyto
All	2	17.315	0.004	H_0: Rejection	All ⇒ dsyto

According to the results in Table 4, agricultural GDP was considered as the dependent variable in the equation created for model 1, and since the p-values 0.05 of the independent variables are greater than the 0.05 significance level, it is concluded that they have no effect on the dependent variable. In other words, the null hypothesis H0, which expresses the absence of the relationship, was accepted. Agricultural machinery per agricultural land was considered as the dependent variable in the equation created for model 2, and since the p-values 0.05 of the variables of the share of agriculture in GDP and the investment in the agricultural sector (public) within fixed capital investments are less than the 0.05 significance level, it is concluded that there is a significant causal relationship from these variables to the dependent variable. No causal relationship was determined for the other independent variables. In the equation of model 3, where nitrogenous fertilizer use is the dependent variable, a significant causal relationship was determined between the variable of agricultural machinery per agricultural land and nitrogenous fertilizer use in the dependent variable direction ($p=0.046$). There is no significant relationship between the other variables and the dependent variable for this model. In Model 4, no significant causal effect of the independent variables on the dependent variable, agriculture's share in GDP, was detected ($P>0.05$). In the equation created for Model 5, the dependent variable was selected as investments in the agricultural sector (public) within fixed capital investments and a significant causality relationship was found between agricultural machinery per agricultural land towards the dependent variable ($P<0.05$). There is no significant relationship for the other variables. Finally, in Model 6, where the variable investment in the agricultural sector (private) within fixed capital investments is the dependent variable, it is observed that there is a significant causal relationship between the variables agricultural machinery per agricultural land and agriculture's share in GDP towards the dependent variable ($P<0.05$). No causal relationship was found between the other independent variables and the dependent variable for this model. In general, it is observed that the variables agricultural machinery per agricultural land and agriculture's share in GDP have a causal relationship towards the dependent variable in many models. This indicates that these variables are important independent variables in the analysis. Other variables do not generally show significant causality.

4. Conclusion

In this research, the economic factors affecting agricultural growth in Türkiye between 1998 and 2022 are analyzed comprehensively. The agricultural sector, as one of the cornerstones of the Turkish economy, makes significant contributions to both economic growth and rural development. In this research, the effects of variables such as fixed capital investments, use of agricultural machinery and fertilization on agricultural growth are analyzed and it is revealed how important roles these variables play in agricultural growth.

The findings of the study show that the impact of fixed capital investments on agricultural growth is significant. While public investments had a decisive role in agricultural growth, especially in the early years of the period under consideration, the impact of private sector investments has become more prominent in recent years. However, the impact of these investments is generally short-term, while more comprehensive and long-term strategic investments are necessary for the sustainability of agricultural growth in the long run. Studies by Roy and Pal (2002) and Fan et al. (2008) also show that fixed capital investments have positive effects on agricultural growth, but private sector investments provide more sustainable growth in the long run.

These findings suggest that public and private sector cooperation should be developed in a balanced manner to support growth in the agricultural sector. In particular, policies such as strengthening agricultural infrastructure, promoting modern agricultural techniques and facilitating access to agricultural finance stand out as critical elements to support the growth of the sector.

The short-term positive impact of agricultural machinery on agricultural growth is noteworthy. Agricultural machinery such as tractors, which are part of mechanized production, increase productivity in production processes and reduce the need for manpower. However, it is determined that the long-term impact of agricultural machinery has diminished and technological innovations need to be integrated into the sector more effectively.

This finding is in line with studies by Anker (1956) and Terin et al. (2013). These studies show that agricultural machinery increases productivity, but for the long-term sustainable growth of the sector, smart agricultural practices and digital technologies need to be widespread in addition to mechanization. In the future, innovative solutions such as AI-powered irrigation systems, sensor-based soil analysis, and agricultural monitoring systems with unmanned aerial vehicles (UAVs) can make agricultural growth more sustainable and efficient. Therefore, smart agricultural technologies and advanced mechanization methods should be further promoted.

Research results show that the use of nitrogen fertilizers has a positive impact on agricultural growth, but this impact is limited compared to other variables. Although fertilization increases yields in the short term, it is not sufficient on its own to support agricultural growth in the long term. Studies by Tıraş (2024) also show that fertilizer use increases productivity, but it needs to be considered together with other factors for sustainable agricultural growth in the long run.

This suggests that fertilizer use should be made more efficient and farmers should be trained on conscious fertilization methods. Furthermore, organic and biological fertilization techniques should be promoted to ensure environmental sustainability.

Another important finding of the study is that the share of agriculture in GDP has tended to decline over time. Despite this, the agricultural sector continues to play a vital role in areas such as job creation, rural development and food security.

In particular, Kopuk and Meçik (2020) find a unidirectional causality from agriculture to economic growth in Türkiye. Similarly, Canbay and Kırca (2020) found that agriculture contributes positively to economic growth, but economic growth can negatively affect the agricultural sector.

Therefore, in order to increase the contribution of agricultural growth to economic growth, incentives and investments in the sector should be planned more effectively and policies targeting rural development should be implemented.

In conclusion, Türkiye needs a comprehensive transformation to support and sustain agricultural growth. Further integration of fixed capital investments, mechanization and technological advances into agricultural production is critical for the sector's long-term growth.

However, promoting environmentally friendly and sustainable agricultural practices, increasing support for organic agriculture and strengthening the integration of agriculture and the food industry will enhance the competitiveness of the sector. Considering the contribution of agriculture not only to economic growth but also to rural development and social welfare, the sector needs to be supported more strongly.

This provides a roadmap for strengthening the Turkish agricultural sector's place in economic growth. The integration of long-term investment strategies, technology-driven transformation and rural development policies will make the agricultural sector more competitive and sustainable in the future. Agriculture is an indispensable sector for both meeting today's economic needs and securing future food security.

Author Contributions

The percentages of the author' contributions are presented below. The author reviewed and approved the final version of the manuscript.

	G.E.
C	100
D	100
S	100
DCP	100
DAI	100
L	100
W	100
CR	100
SR	100
PM	100

C= concept, D= design, S= supervision, DCP= data collection and/or processing, DAI= data analysis and/or interpretation, L= literature search, W= writing, CR= critical review, SR= submission and revision, PM= project management.

Conflict of Interest

The author declared that there is no conflict of interest.

Ethical Consideration

Ethics committee approval was not required for this study, as it did not involve any research on humans or animals.

References

Akmal N, Rehman B, Ali A, Shah H. 2012. The impact of agriculture credit on growth in Pakistan. Asian J Agri Rur Dev, 2(4): 579–583.

Akram N, Hussain Z. 2008. Agricultural credit and economic growth in Pakistan: An empirical analysis. Pakistan Eco Sci Rev, 46(2): 141-158.

Aktaş C. 2010. An analysis of the relationship between the real exchange rate and export and import in Turkey using the var methodology. Inter J Man Eco Busi, 6(11): 123–140.

Ammani AA. 2012. An investigation into the relationship between agricultural production and formal credit supply in Nigeria. Inter J Agri For, 2(1): 46-52.

Anker DLW. 1956. The results of the mechanization of agriculture. Ankara Uni Fac Politic Sci J, 11(1): 20-40.

Anthony E. 2010. Agricultural credit and economic growth in Nigeria: An empirical analysis. Busi Eco J, 10:1-7.

Apaydın Ş. 2018. The effects of bank loans on economic growth in Turkey. Ömer Halisdemir Univ J Fac Eco Administ Sci, 11(4): 15-28.

Bağcı A. 2022. Economic growth and smart agriculture: Examples from Turkey and the world. In: Kacır MF, Şeker M, Doğrul M, editors. National Technology Move.Turkish Academy of Sci, Ankara, Türkiye, pp: 142.

Benfica R, Cungura B, Thurlow J. 2019. Linking agricultural investments to growth and poverty: an economywide approach applied to Mozambique. Agri Sys, 172: 91- 100.

Burbidge J, Harrison A. 1985. An historical decomposition of the great depression to determine the role of Money. J Mon Eco, 16(1): 45-54.

Canbay Ş, Kırca M. 2020. Türkiye'de sanayi ve tarim sektörü faaliyetleri ile iktisadi büyüme arasindaki ilişkiler: kaldor büyüme yasasinin analizi. İnsan Toplum Bilim Araş Derg, 9(1): 143-170. https://doi.org/10.15869/itobiad.663654

Cömertler Şimşir N. 2012. An econometric analysis of the relationships between economic growth and agricultural credits for propoor growth in turkey. Inter J Soci Sci Hum Studi, 4(2): 355-364.

Çetin M, Ecevit E. 2015. The relationship between agricultural credits and agricultural production: The example of Türkiye. J Agri Eco, 21(1): 29-38.

Çevik Z, Zeren F. 2014. Examining the effect of agricultural credits on financial development with asymmetric causality test. J Man Eco Res, 12(24): 197-208.

Das A, Senapati M, John J. 2009. Impact of agricultural credit on agriculture production: an empirical analysis in India. Reserve Bank of India Occasional Papers, 30(2): 75-107.

Demir A, Özcan B. 2019. The impact of agricultural credits on agricultural production in Turkey: A cointegration analysis. J App Eco, 22(1): 45-60.

Duramaz S, Taş T. 2018. The effect of agricultural loans used by public, private and foreign capital banks and agricultural capital banks on agricultural production: Panel data analysis for the Aegean Region. Inter J Mana Eco Busi, 14(1): 35-50.

Ekwere GE, Edem ID. 2014. Evaluation of agricultural credit facility in agricultural production and rural development. Global J Human Sci: B Geography, Geo-Sci Envir Disas Mana, 14(3): 19-26.

Fan S, Gulati A, Thorat S. 2008. Investment, subsidies, and pro-poor growth in rural India. Agri Eco, 39:163–170.

Glynn J, Nelson P, Reetu V. 2007. Unit root tests and structural breaks: A survey with applications. Revista Metod Cuantita Para La Economia Y La Empresa, 3: 63–79.

Gujarati D. 2011. Econometrics by example. Palgrave Macmillan, London, UK, pp: 124.

Gülçubuk B. 2005. Nature first, people first. URL: www.bugday.org/article.php?ID=758, (accessed date: December 20,2024).

Iganiga BO, Unemhilin DO. 2011. The impact of federal government agricultural expenditure on agricultural output in Nigeria. J Eco, 2(2): 81-88.

Kadanalı E, Kaya E. 2020. Agricultural loan and agricultural production value in Turkey. Alınteri Zirai Bilim Derg, 35(1): 93-98.

Kaya O, Kaya I, Gunter L. 2012. Development aid to agriculture and economic growth. Rev Develop Eco, 16(2): 230-242

Kılıçarslan O, Dinç O. 2007. Türkiye ekonomisinde teknoloji ve veri transferi. GAU J Soc Appl Sci, 3(5): 73-75.

Koç AA, Yu TE, Kıymaz T, Sharma BP. 2019. Effects of government supports and credits on Turkish agriculture: A spatial panel analysis. J Agri Dev Eme Eco, 9(4): 391-401.

Kopuk E, Meçik O. 2020. The impact of manufacturing industry and agricultural sectors on economic growth in Turkey: Analysis of the period 1998-2020. Mana Eco J, 27(2): 263-274.

Köse Z, Meral G. 2021. A review on the relationship between agricultural supports, food security and economic growth in Turkey. Studies Soci Sci Ins,1(2): 51-73.

Merdan K. 2023. Economic factors affecting agricultural growth in Turkey a regression analysis. Karamanoğlu Mehmetbey U0niversity J Soc Eco Res, 25(45): 1125-1142.

Mert M, Çağlar, AE. 2019. Eviews ve Gauss uygulamali zaman serileri analizi. Detay Yayıncılık, Ankara, Türkiye, ss: 68.

Nelson CR, Plosser CI. 1982. Trends and random walks in macroeconomic time series. J Mon Eco, 10(1982): 139-162.

Okine E, Özel R. 2018. Agriculture and economic growth in Republic of Ghana. Harran Tarım Gıda Bilim Derg, 22(3): 363-375.

Olagunju FI, Adeyemo R. 2007. Agricultural credit and economic growth in Nigeria: An empirical analysis. J Soc Sci, 15(2): 107-114.

Önder F. 2023. The impact of agricultural credits on growth in Turkey: a panel data estimation. Turkish J Agri Nat Sci, 10(4): 1039-1050.

Özaydın G, Çelik Y. 2019. Tarım sektöründe arge ve inovasyon. Tarım Ekon Derg, 25(1): 1-13. https://doi.org/10.24181/tarekoder.464556

Özen A, Ülger M, Kıdemli M. 2024. Türkiye'de insani gelişme, kentleşme, sanayinin gelişimi, tarımsal gelişme ve karbon emisyonu ilişkisi. Turk Stud - Ecofd, 19(4): 1431-1446. https://dx.doi.org/10.7827/TurkishStudies.77741

Rahman MW. 2011. Policies and performances of agricultural/rural credit in Bangladesh: What is the influence on agricultural production. African J Agri Res, 6(31): 6440 - 6452.

Roy BC, Pal S. 2002. Investment, agricultural productivity and rural poverty in India: A state level analysis. Indian J Agri Eco, 57(4): 653-678.

Sarı A. 2008. The effectiveness of automatic equalization mechanisms in ensuring the balance of payments in Turkey according to the monetarist view. CÜ J Eco Admin Sci, 9(2): 1-12.

Şaşmaz MÜ, Özel Ö. 2019. The impact of financial incentives provided to the agricultural sector on the development of the agricultural sector: The case of Turkey. Dumlupınar Univ J Soc Sci, (61): 50-65.

Subaşı O, Ören M. 2013. Agricultural R&D expenditures and agricultural growth relations in Turkey. Akdeniz Univ J Fac Agri, 26(2): 99-104.

Taban S, Kar M. 2016. Kalkınma ekonomisi. Ekin Yayınevi, Bursa, Türkiye, ss: 58

Tan S, Atak Ş, Şengül Ü, Tan SS. 2015. The evaluation of the changes in the agricultural sector with common economic indicators in Turkey during the last decade. Mediterranean J Soc Sci, 6(2): 588-595.

Terin M, Aksoy A, Güler İO. 2013. A study on determining the economic factors affecting agricultural growth. Iğdır Univ J Sci Inst, 3(3): 41-50.

Tıraş HH. 2024. The effect of agricultural fertilizer and pesticide use on agricultural GDP in leading countries in agricultural production; panel data analysis research. BMIJ 12(1): 132-147

Toda HY, Yamamoto T. 1995. Statistical inference in vector autoregressions with possibly integrated processes. J Eco, (66): 225-250.

Tuan Anh N, Gan C, Anh DLT. 2020. Does credit boost agricultural performance? Evidence from Vietnam. Inter J Soc Eco, 47(9): 1203-1221.

Ülger, M. 2025. E-7 ülkelerinde tarim, sanayi ve ekonomik büyüme çevresel bozulmaya neden olur mu? Turkish J Agri Nat Sci, 12(1): 28-39. https://doi.org/10.30910/turkjans.1574840

Yalçınkaya, H. 2018. Determination of the effect of agricultural credits on the economy by using granger causality analysis. J Infor Eco Man, 13(1): 51-61.

Yıldız E, Oğuzhan A. 2007. Effect of monetary policies implemented in Turkey on agricultural production: model testing. Trakya Univ J Soc Sci, 9(2): 206-225.

Black Sea Journal of Agriculture

doi: 10.47115/bsagriculture.1614694

Open Access Journal
e-ISSN: 2618 - 6578

Research Article
Volume 8 - Issue 2 : 217-224 / March 2025

OPTIMIZING FOAM PROPERTIES OF EGG WHITE POWDER-BASED FOAM SYSTEM BY RESPONSE SURFACE METHODOLOGY

Mehmet GÜLDANE[1]*

[1]*Sakarya University of Applied Sciences, Pamukova Vocational School, Program of Laboratory Technology, Sakarya, Türkiye*

Abstract: Foam is a thermodynamically unstable multiphase system consisting of a continuous liquid and discontinuous air phases. Therefore, the interfaces between the air and water phases need to be stabilized by surfactant components. For this purpose, egg white proteins are the most widely used interfacial agent in the food sector; however, the foaming properties of egg white powders produced for technological purposes are negatively affected by thermal treatment. Thus, in this study, the impact of process variables such as saponin extract (0.05-0.15%), guar gum (0.1-0.4%), and mixing time (3-9 min) on foaming capacity (FC) and foam stability (FS) was investigated using response surface methodology via Box-Behnken design to enhance the foaming characteristics of protein powders. The analysis of variance results demonstrated that all process parameters had a highly significant effect on the quadratic FC model. However, it was found that the effect of guar gum on the FS model was dominant ($P < 0.05$). Furthermore, the results showed that increasing saponin content and mixing time, as well as guar gum and mixing time resulted in increased values of FC and FS, respectively. Moreover, Design Expert 13.0 was used as a statistical tool to perform multi-response optimization of both responses via the desirability function approach. The findings indicated that the optimal combination for maximizing responses was at 0.15% saponin content, 0.37% guar gum, and 9 min of mixing time.

Keywords: Optimization, Box-Behnken design, Foaming capacity, Foam stability, Egg white powder

***Corresponding author:** Sakarya University of Applied Sciences, Pamukova Vocational School, Program of Laboratory Technology, Sakarya, Türkiye
E mail: mehmetguldane@subu.edu.tr (M. GÜLDANE)
Mehmet GÜLDANE https://orcid.org/0000-0001-7321-0496

Received: January 06, 2025
Accepted: February 26, 2025
Published: March 15, 2025

Cite as: Guldane M. 2025. Optimizing foam properties of egg white powder-based foam system by response surface methodology. BSJ Agri, 8(2): 217-224.

1. Introduction

Foam can be defined as a multiphase system formed by trapping gas bubbles in a liquid phase. Such systems are thermodynamically unstable, and therefore maintaining the equilibrium between the two phases is of great importance for practical applications. Reducing the surface tension between the liquid and gas interface in a food foam is one of the most important parameters in foam production. For this purpose, saponins and/or proteins with a foaming ability are commonly used (Kezwon and Wojciechowski, 2014). Egg white is the most widely used foaming material in food processing. To meet the industrial demand for egg albumen, egg whites are usually dried using a spray drying method to produce egg white powder (EWP). However, this process generally causes a reduction in the foaming properties of proteins in EWP. Therefore, further research is still needed to improve the foaming properties of EWP (Chang et al., 2020).

Numerous studies have been conducted on the influence of colloidal materials on the properties of protein-based foams. Hydrocolloids exert this effect by increasing the viscosity of the continuous phase and altering the structural, rheological, and amphipathic characteristics of proteins (Li et al., 2023). Therefore, the features of the gums might affect the distribution of the bubbles in liquid matrices in the foam formulations and this might alter the air fraction, as well as the density of the foam system (Ptaszek et al., 2014). Guar gum is considered to be a non-ionic colloidal saccharide obtained from the *Cyamopsis tetragonolobus* (Hamdani et al., 2018). Compared with other commercially available gums, guar gum has a relatively higher molecular weight and a larger hydration ability. Thus, it affects the foaming characteristics of protein foams by substantially increasing the viscosity of the foam solution (Dickinson, 2011).

Saponins are used in formulations where rapid foam formation is desired since they adsorb at air/water interfacial films faster than globular proteins. In the food industry, saponin components are preferred to obtain stable foam in certain confectionery products (e.g., halva, meringue, marshmallow, etc.), beers, and some carbonated beverages. In comparison to saponins, proteins have been shown to contribute considerably to the FS by increasing the elasticity of interfacial films during the adsorption process at foam interfaces. Consequently, the incorporation of saponins and proteins in such systems has been shown to enhance foam properties through synergistic interactions (Wojciechowski et al., 2014). *Gypsophila spp.* possess notable concentrations of saponins within their rhizomes. It was reported that the substitution of egg white with soapwort extract at a ratio of 50% and 75% did not result in a significant change in the physical characteristics of the sponge cake dough (Çelik et al., 2007).

Foaming capacity (FC) and foam stability (FS) are the most important parameters in the assessment of the quality evaluation of food foams. The FC refers to foamability which indicates the amount of air trapped in the foam structure. However, The FS provides information about the period of time the trapped air is retained in the foam structure. The performance of protein foams depends on a combination of internal factors, such as the structure and composition of the protein, and external parameters, such as environmental factors and processing techniques (Indrawati et al., 2008). Thus, it is essential to define the parameters involved in the production of foam and then optimize the process using an appropriate methodology. Response Surface Methodology (RSM) is an empirical modeling approach that integrates statistical and mathematical methods to describe the relationship between response variables and input factors. RSM provides significant advantages, especially in chemical and biological processes where several process variables impact the response. However, it is critical to select an appropriate experimental design to evaluate the effects of process factors on the target variable (Rawat et al., 2024).

Therefore, the objective of this study was to enhance the foaming properties of EWP-based foam using a BBD with RSM. Accordingly, the quality properties of the resulting foams produced by mixing pre-foaming solutions containing various concentrations of saponin extract (0.05-0.15%), guar gum (0.1-0.40%), and different times (3-9 min) were optimized using the RSM. The findings are expected to contribute to the development of improved foaming systems for food industry applications.

2. Materials and Methods

2.1. Material

The EWP and guar gum were supplied by Tito (Izmir, Türkiye). The root of *Gypsophila arrostii var. nebulosa* was procured from a local store in Sakarya, Türkiye. The materials were stored at room temperature. The chemicals used in this research were analytical grade and were of obtained from Sigma-Aldrich (Germany).

2.2. Preparation of Biopolymer Solutions

A total of 20 g of protein powder was gradually transferred to 100 mL of distilled water, which was stirred in a magnetic stirrer (Heidolph MR Hei-Tec, Scwabach, Germany) at 400 rpm. The mixture was left to dissolve for a total of 2 h. The guar gum solution was prepared as 0.5% (w/v) under conditions similar to those described above. Until foam production, the protein powder was stored under refrigerator conditions, while the guar gum solution was mixed at 200 rpm for 12 h at room temperature.

2.3. Saponin Extraction

The saponin extract was prepared from *Gypsophila bicolor* according to the method proposed by Güldane (2023). This method involves subjecting the powdered sample to an extraction process using a soxhlet apparatus for a period of eight hours. Following the extraction process, the saponin extract was stored in an amber glass bottle in the refrigerator. This step was performed after the removal of insoluble components from the solution.

2.4. Foaming Procedure

The production of model foams was carried out in accordance with the specifications outlined in table 2. Throughout the process of foam production, the protein content of the samples was maintained at a constant level of 5% (w/v). Accordingly, 20% protein solution, saponin extract (0.05-0.15%), and guar gum solution (0.1-0.4%) were added into a beaker in calculated amounts, yielding a total of 200 mL solution. This prefoaming mixture was subsequently exposed to a mixing process for 10 min at a speed of 200 rpm using a magnetic stirrer at room temperature. Subsequently, the resulting mixture was whipped using a domestic mixer (Kenwood KM070, England) at 158 rpm at various times (3-9 min). The final foam was analyzed immediately following the whipping process.

2.5. Statistical Analysis

2.5.1. Foaming capacity (FC)

Once the whipping process was completed, the mixing apparatus was gently removed, and the foam sample was poured into the preweighed measuring cup. The surface of the samples was leveled with a plastic spatula and the weights were recorded. The FC values of the samples were then calculated by the following equation 1 (Wang et al., 2015).

$$FC\ (\%) = \frac{(m_s - m_f)}{m_f} \times 100 \qquad (1)$$

where m_s and m_f indicate the weights of the prefoaming solution and the foam, respectively.

2.5.2. Foam stability (FS)

The stability of the model foams determined by the procedure proposed by Güldane (2023). The values for FS were given in min.

2.6. Experimental Procedure

In the current study, the BBD with RSM was used to optimize selected operational parameters, which have an influence on the foaming properties of EWP. RSM is a multivariate statistical approach that can be a useful tool for the interpretation and analysis of experimental data involving more than one variable. It is especially useful in developing regression-based response surface models, which facilitate experimental optimization and predictive analysis (Li et al., 2024).

The RSM experiments were developed using Design Expert software (ver. 13.0, Stat-Ease Co., Minneapolis, MN, USA) based on the BBD model. The process factors with corresponding levels used for the RSM experiments are given in table 1. The experiments consist of three factors with three levels and fifteen response surface tests that include three center points are summarized in table 2. The present research investigated the effects of saponin extract (A, 0.05-0.15%), guar gum (B, 0.10-0.40), and mixing time (C, 3-9 min) on key response variables, FC and FS, using a second-order polynomial equation (equation 2) to establish correlations between the variables.

$$Y = \beta_0 + \sum_{j=1}^{k} \beta_j x_j + \sum_{j=1}^{k} \beta_{jj} x_j^2 + \sum_{i=1}^{k} \sum_{j \neq i}^{k} \beta_{ij} x_i x_j + \varepsilon \qquad (2)$$

where Y is the response variable, β_j, β_{ij} and β_{jj} refer to the coefficients of linear, interaction and quadratic terms, respectively.

Table 1. Process factors and levels

Process variables	Unit	Symbol	Level		
			-1	0	+1
Saponin extract	%	A	0.05	0.1	0.15
Guar gum	%	B	0.1	0.25	0.40
Mixing time	min	C	3	6	9

Statistical analysis was conducted using Design Expert software, which produced three-dimensional surface response plots derived from the polynomial equations based on experimental data. These plots offer a visual representation of the interaction between process variables and response outcomes. The significance of the model was evaluated through analysis of variance (ANOVA), with the statistical relevance of linear, quadratic, and interaction terms determined using Fisher's F-test and associated p-values. The coefficient of determination (R^2) was calculated to evaluate the accuracy and reliability of each model.

Table 2. Box-Behnken design (BBD) matrix and experimental results

No	Process variables			Experimental results	
	Saponin extract %	Guar gum %	Mixing time min	Foaming capacity (FC)	Foam stability (FS)
1	0.05	0.25	3	712.0 ± 12.25	44.99 ± 1.24
2	0.15	0.25	3	468.0 ± 10.22	52.38 ± 1.45
3	0.10	0.25	6	329.0 ± 8.34	59.46 ± 1.89
4	0.15	0.1	6	629.5 ± 15.00	55.26 ± 0.26
5	0.15	0.40	6	632.4 ± 14.23	53.56 ± 1.85
6	0.05	0.25	9	538.2 ± 12.45	46.54 ± 0.80
7	0.10	0.25	6	824.6 ± 14.80	58.61 ± 0.65
8	0.10	0.25	6	542.0 ± 13.00	74.35 ± 1.53
9	0.10	0.40	3	644.4 ± 8.25	53.95 ± 0.41
10	0.05	0.40	6	447.8 ± 10.25	45.31 ± 0.26
11	0.10	0.40	9	399.4 ± 9.54	67.0 ± 1.00
12	0.05	0.1	6	598.7 ± 11.50	51.3 ± 0.54
13	0.10	0.1	3	468.9 ± 13.40	46.11 ± 0.23
14	0.15	0.25	9	648.4 ± 12.84	48.44 ± 0.46
15	0.05	0.1	9	619.4 ± 10.43	69.3 ± 1.12
Minimum	-	-	-	329.0	44.99
Maximum	-	-	-	824.6	74.35

4. Results and Discussion

3.1. Model Fitting

In the study, a BBD was conducted to improve the foaming properties of EWP. A total of fifteen experiments with three center points were carried out in the laboratory to determine optimal levels of the process factors. The mean experimental results obtained from the experiments are presented in table 2. The data was analyzed by using Design Expert 13 software to develop an optimal empirical model that established a relationship between the foaming characteristics, FC and FS, and the selected foaming process variables, saponin extract, guar gum, and mixing time. The fitted quadratic equations for FC (equation 3) and FS (equation 4) are given below.

$$FC = +635.43 + 59.95A - 57.08B + 130.13C + 8.10AB + 56.25AC + 6.55BC - 20.22A^2 - 83.22B^2 - 25.17C^2 \qquad (3)$$

$$FS = +54.26 + 1.28A + 10.60B + 2.62C + 1.36AB + 3.39AC + 2.54BC + 1.08A^2 + 3.74B^2 - 3.24C^2 \qquad (4)$$

The results obtained for the FC and FS from the foaming experiment were analyzed using an analysis of variance to illustrate the validation of the obtained experimental result. The statistical significance and adequacy of the developed model were determined by the statistical tools, F value and P value, which were derived from the sum of squares (SS) and mean squares (MS) statistics. A higher F-value and a lower P-value than 0.05 indicate the statistical significance of the effect of the relevant parameter on the response variable (Dang et al., 2024). The ANOVA results in table 3 summarize the statistical significance of the effects of process parameters (saponin extract, guar gum, and mixing time) and their interactions on FC. The F-value of 137.37 and the P-value ($P < 0.0001$) of the model show that the developed model for the FC is highly significant. However, the coefficient of determination (R^2) values (R^2=0.9960 and R^2_{adj}=0.9887) of this model indicate that the data fit the model. The linear (A, B, C), interaction (A*C) and quadratic (B*B and C*C) terms have a significant impact on FC.

Table 3. ANOVA results for FC

Source	SS	Df	MS	F-value	P-value
Model	230800.00	9	25646.79	137.37	< 0.0001
A-Saponin extract	28752.02	1	28752.02	154.00	< 0.0001
B-Guar gum	26060.45	1	26060.45	139.58	< 0.0001
C-Mixing time	135500.00	1	135500	725.54	< 0.0001
A*B	262.44	1	262.44	1.41	0.2890
A*C	12656.25	1	12656.25	67.79	0.0004
B*C	171.61	1	171.61	0.9192	0.3817
A*A	1509.10	1	1509.10	8.08	0.0361
B*B	25569.28	1	25569.28	136.95	< 0.0001
C*C	2338.56	1	2338.56	12.53	0.0166
Lack-of-fit	808.71	3	25646.79	137.37	< 0.0001
R^2	0.9960		269.57	4.32	0.1937
Adjusted R^2	0.9887				

SS= sum of squares; DF= degree of freedom; MS= mean square.

In the same context, the ANOVA result of the FS model is presented in table 4, which shows that the P-value is desirable, thereby resulting in excellent significance of the regression model. The higher R^2 values (R^2=0.9843 and R^2_{adj}=0.9561) and insignificant lack of fit ($P > 0.1271$) demonstrate that the FS response can be explained by the model terms. The analysis indicates that among all the process parameters, guar gum is the most critical factor influencing the FS response, as supported by a P-value less than 0.0001 and an F-statistics value of 245.65. Furthermore, the linear effect of mixing time, the interaction effect of guar gum and mixing time (B*C), and the quadratic effect of guar gum (B*B) and mixing time (C*C) on FS are found to be significant. On the other hand, all the terms for saponin extract except the interaction effect of A and C have no meaningful impact on the FS.

Table 4. ANOVA table for FS

Source	SS	Df	MS	F- value	P-value
Model	1148.82	9	127.65	34.86	0.0006
A-Saponin extract	13.21	1	13.21	3.61	0.1160
B-Guar gum	899.52	1	899.52	245.65	< 0.0001
C-Mixing time	54.86	1	54.86	14.98	0.0118
A*B	7.43	1	7.43	2.03	0.2137
A*C	46.04	1	46.04	12.57	0.0165
B*C	25.81	1	25.81	7.05	0.0452
A*A	4.32	1	4.32	1.18	0.3270
B*B	51.76	1	51.76	14.14	0.0132
C*C	38.66	1	38.66	10.56	0.0227
Lack-of-fit	16.72	3	5.57	7.03	0.1271
R^2	0.9843				
Adjusted R^2	0.9561				

SS= sum of squares; DF= degree of freedom; MS= mean square

3.2. Effect of Process Factors on Response Variables

The 3D response surface plots in figure 1 to 6 illustrate the relationship between the FC and FS and the process parameters such as saponin extract, guar gum, and mixing time. These plots offer valuable insights into the interactions between saponin extract (A) and guar gum (B), and their impact on the foaming properties.

Figure 1 provides a visual representation of the impact of saponin extract (A) and guar gum (B) on the FC while maintaining a constant mixing time (C) at 6 min, representing the midpoint value. Initially, as both saponin extract and guar gum increase, the FC also increases, suggesting improved foaming properties. However, beyond certain optimal levels of guar gum, further increases lead to an increase in foam density. The graph illustrates that the highest FC value is achieved at concentrations of saponin extract and guar gum of 0.15% and 0.22%, respectively. In a related study, Çelik et al., (2007) reported that the interaction between EWP and soapwort saponins improved the sensory properties of the foam-based product. In a previous study, Chauhan et al., (1999) observed a deterioration in the interfacial properties of quinoa proteins, including foaming and emulsifying, resulting from the removal of saponins from the proteins. The results from dynamic interfacial tension studies demonstrated that the saponin from quillaja bark adsorbs to the air/water interface in a foam system more rapidly than β-casein proteins, thereby promoting foaming by reducing interfacial tension (Wojciechowski et al., 2014).

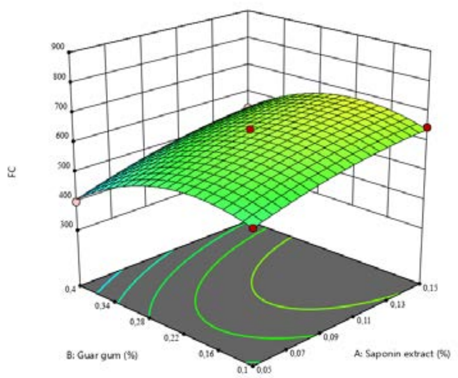

Figure 1. Effect of saponin extract and guar gum on FC.

Figure 2 depicts a relatively linear plane with a slight incline, indicating that both saponin extract and mixing time positively influenced the FC. As saponin extract and mixing time increase, the FC increases consistently, suggesting that higher saponin content and longer mixing improve the foamability of EWP. Foam formation is induced by mechanical agitation of the pre-foaming solution, which causes partial denaturation of the proteins and improvement in interfacial properties (Campbell and Mougeot, 1999). Thus, the foaming potential of a protein solution is measured as the amount of air that can be incorporated into its structure during whipping (Farid et al., 2023).

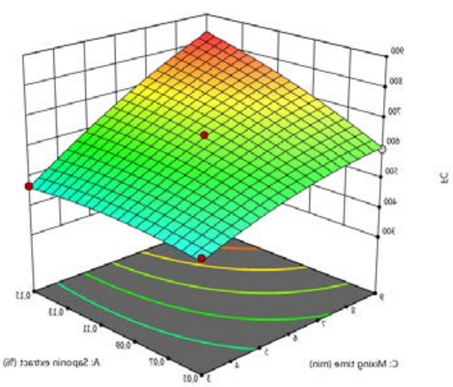

Figure 2. Effect of saponin extract and mixing time on FC.

The interaction effect of guar gum and mixing time on FC, with the saponin extract was maintained at its midpoint of 0.10% is shown in figure 3. It is clear that increasing mixing time in the foaming process increased the foamability of the EWP-base foam model owing to the aeration of the foam system. In contrast, the FC increases slightly as the concentration of hydrocolloid rises from 0.10% to 0.25%. However, a further increase in gum from 0.25% to 0.40% leads to a slight decline in the foaming ability of the foam system. The addition of saccharides into the foaming system causes an increase in viscosity and thus negatively affects the foamability of the pre-foaming solution (Sadahira et al., 2018).

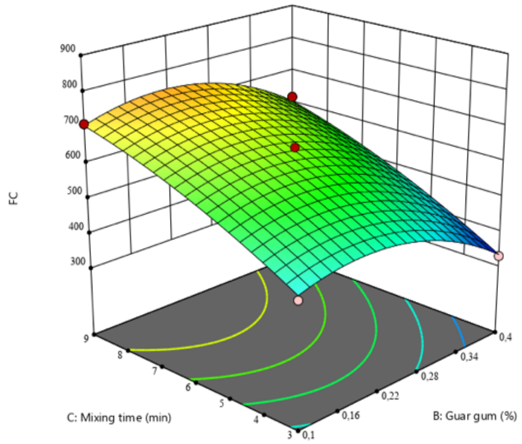

Figure 3. Effect of guar gum and mixing time on FC.

The interactive influence trend of saponin extract and at guar gum on FS in the EWP base foam system is illustrated in figure 4. It can be deduced from the graph that increasing the level of guar gum has a substantial and saponin extract has a positive impact on the FS value. However, the change in the level of hydrocolloid has shown a remarkable effect on the stability of the EWP base foam system than the concentration variation of the surfactant. Similar findings were reported by Tang et al. (2022), who investigated the effects of egg white powder modification with soy peptides on the batter stability of angel food cake. The researchers reported an increasing trend in stability with increasing sucrose concentration up to 36 g/100 ml.

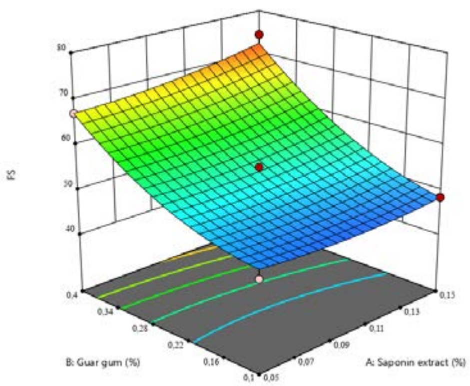

Figure 4. Effect of saponin extract and guar gum on FS.

The hydrocolloid substances play a critical role in FS by binding water molecules within the foam matrix. It has been demonstrated that this action increases the viscosity of the medium, thereby reducing the mobility of water and mitigating water leakage (drainage) from the foam structure. This, in turn, contributes to enhancing the overall structural integrity of the foam (Dickinson 2003). A rheological study conducted by Liszka-Skoczylaset al., (2014) demonstrated that viscosity was a predominant eterminant in whey protein concentrate (WPC)/non-ionic guar gum base foam system. Similarly, Tan et al., (2015) stated a positive correlation between viscosity and FS in WPC foams.

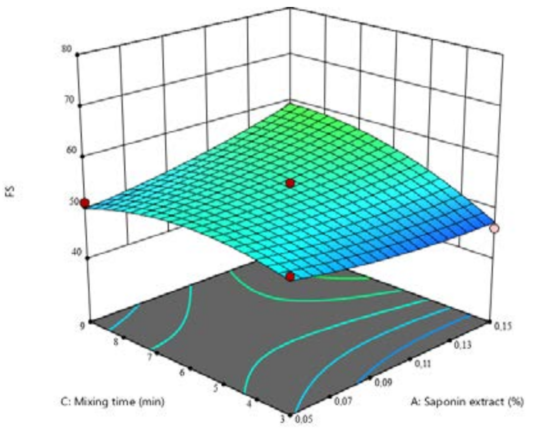

Figure 5. Effect of saponin extract and mixing time on FS.

In figure 6, the impact of guar gum and mixing time on the FS is depicted while maintaining the concentration of saponin extract at 0.15%. It is evident that with an increase in hydrocolloid content, the FS also increases. However, it is noteworthy that beyond a certain whipping time threshold, no substantial enhancement in stability is observed.

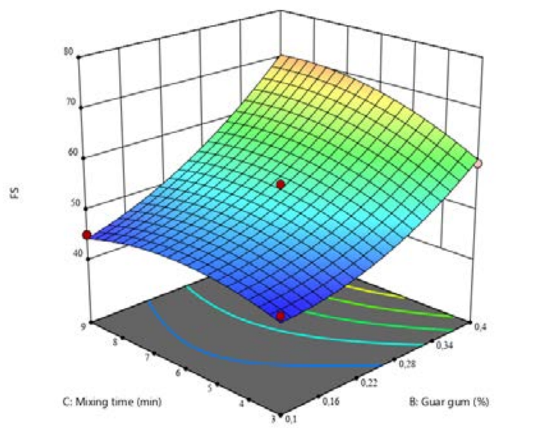

Figure 6. Effect of guar gum and mixing time on FS

Figure 6 also revealed that the maximum FS value can be achieved by selecting levels of guar gum and mixing time of 0.4% and 8 min, respectively. In protein-based foams, the size of bubbles has been shown to have a substantial impact on the stability of the foam. In the EWP/hydroxypropyl methylcellulose foam system, the foams with smaller bubbles have been observed to demonstrate enhanced stability in comparison to those with large and irregular bubble dimensions (Sadahira et al., 2018). Consequently, it has been proposed that prolonging the whipping process leads to the formation of a foam with smaller bubbles that are of similar size in a viscous medium. This, in turn, has been shown to enhance the FS.

3.3. Optimization and Confirmation

In order to optimize the response variables (FC and FS) simultaneously, the desirability function approach was applied. The application of process optimization with desirability functions was introduced by Derringer and Suich (1980). The fundamental principle of the method is to identify "target" operating conditions as the optimal response value. Thus, each response is transformed into an individual desirability function (d_i), which ranges from 0 to 1 (Malghan et al., 2017). However, RSM is often integrated with a desirability function in order to convert the desirability index values of the responses into an overall desirability (D) value (Chiu et al., 2022). The following steps were carried out in the optimization of the foam properties of the EWP-based foam system.

i) The objective of this study was to optimize the FC and FS characteristics. Thus, the d_i value for all responses was computed for each set of experiments using the "larger the better" criterion according to the following equation 5.

$$\begin{cases} 0 & y < L \\ \left(\frac{y-L}{T-L}\right)^r, & L \leq y \leq T \\ 1 & y > T \end{cases} \quad (5)$$

where L and T represent the lower and upper values of the response variables, respectively, while the parameter r refers to the weight value.

ii) The d_i values were then combined, and the overall desirability value (D) was computed using equation 6.

$$D = \left(d_1^{w_1} \times d_2^{w_2}\right) = \left(\prod_{i=1}^{2} d_i^{w_i}\right)^{1/n} \quad (6)$$

iii) optimal process parameter levels are determined by maximizing the overall desirability values (Kumar et al., 2018).

The desirability function approach integrated with RSM was used to determine the overall desirability value. For this purpose, Design Expert 13.0 software, as a statistical tool, was used to maximize the foaming properties of the EWP-based foam system. The equal weight values for FC and FS were assigned. The index values for FC and FS were calculated by a numerical optimization tool as 0.831 and 1, respectively. Furthermore, the maximum overall desirability (D=0.912) corresponds to the optimal values of the process parameters, i.e., 0.377% guar gum, 9 min mixing time, was identified. Figure 7 shows the optimal parameter settings and predicted response values with red and blue dots, respectively. As illustrated in figure 7, the optimal parameter settings and predicted response values are represented by red and blue dots, respectively. As shown in figure 7, the FC and FS values were predicted as 740.931% and 74.35 min, respectively. To validate the values predicted by RSM, the EWP base foam was produced at the optimal values for the process parameters. Following the performance of three replicate analyses under optimal conditions, the FC and FS values were determined to be 708.32% and 70.86 min, respectively. As the deviations between the observed and predicted values were found to be within 5%, it was concluded that the developed regression model was successful in optimizing the foaming properties of EWP-based foam. Considering the process parameters, the optimization process provides valuable insights into the utilization of response surface methodology as a statistical tool for improving the foaming properties of egg white powder.

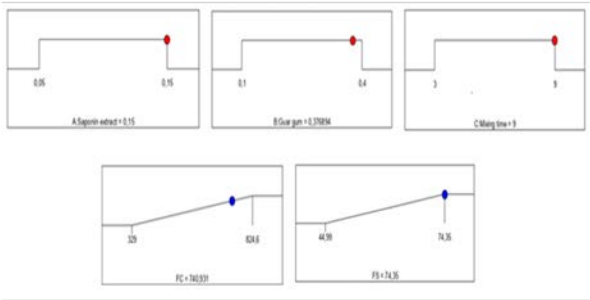

Figure 7. Ramps plot for process factors and responses.

4. Conclusion

The foaming parameters for egg white powder were successfully optimized using response surface methodology with Box-Behnken design. A total of fifteen experiments with three center points were conducted to optimize process factors, including saponin extract, guar gum, and mixing time. Following this, an analysis of variance was performed to develop quadratic models and investigate the impact of each process parameter on the. responses, foaming capacity, and foam stability. The findings indicated a correlation between foaming capacity and all process parameters, while foam stability was found to be associated with guar gum and mixing time. To further explore the synergistic interaction effect between process variables on the selected responses, 3D plots were employed. Multiple response optimization was then executed via a desirability function approach, employing Design Expert software. Confirmation experiments were conducted at optimal process conditions, i.e., 0.15% saponin extract, 0.37% guar gum, and 9 min mixing time. The experimental results obtained in this study were consistent with the predicted results, indicating that there were no statistically significant differences between predicted and observed data. Future research should explore the effect of the interactions with different saponin and/or protein sources on the foam properties of egg white protein powder. Moreover, the impact of optimal foams on final product properties in real food systems must be investigated.

Author Contributions

The percentages of the author' contributions are presented below. The author reviewed and approved the final version of the manuscript.

	M.G.
C	100
D	100
S	100
DCP	100
DAI	100
L	100
W	100
CR	100
SR	100
PM	100
FA	100

C= concept, D= design, S= supervision, DCP= data collection and/or processing, DAI= data analysis and/or interpretation, L= literature search, W= writing, CR= critical review, SR= submission and revision, PM= project management, FA= funding acquisition.

Conflict of Interest

The author declared that there is no conflict of interest.

Ethical Consideration

Ethics committee approval was not required for this study because there was no study on animals or humans.

References

Campbell GM, Estelle M. 1999. Creation and characterisation of aerated food products. Trends Food Sci, 10(9): 283-96.

Chang C, Yali X, Mingcheng S, Yujie S, Xin L, Junhua L, Yanjun Y. 2020. Effect of dry-heat and guar gum on properties of egg white powder: analysis of forming capacity and baking performance. Food Hydrocoll, 99: 105333.

Chauhan GS, Cui W, Eskin NAM. 1999. Effect of saponin on the surface properties of quinoa proteins. Int J Food Prop, 2(1): 13-22.

Chiu JE, Chau SW, Shih WL. 2022. Multi-response optimization of IC wire bonding for large probe marks by the RSM and desirability function approach. Int J Adv Manuf Tech, 123(7-8): 2719-31.

Çelik I, Yusuf Y, Fatma I, Özlem Ü. 2007. Effect of soapwort extract on physical and sensory properties of sponge cakes and rheological properties of sponge cake batters. Food Chem, 101(3): 907-11.

Dang X, Maged A, Tao L, Salah TAM. 2024. Single and multi-response optimization of scroll machining parameters by the Taguchi method. Int J Precis Eng Manuf, 25(8): 1601-14.

Derringer G, Suich R. 1980. Simultaneous optimization of several response variables. J Qual Technol, 12(4): 214-219.

Dickinson E. 2003. Hydrocolloids at interfaces and the influence on the properties of dispersed systems. Food Hydrocoll, 17(1): 25-39.

Dickinson E. 2011. Mixed biopolymers at interfaces: competitive adsorption and multilayer structures. Food Hydrocoll, 25(8): 1966-83.

Farid E, Sabah M, Hassan S, Sherif E, Eman T. 2023. Effect of soy protein isolate concentration and whipping time on physicochemical and functional properties of strawberry powder. J Food Meas Charact, 17(4): 3815-26.

Güldane M. 2023. Optimizing foam quality characteristics of model food using Taguchi-based fuzzy logic method. J Food Process Eng, 46(8): e14384.

Hamdani AM, Idrees AW, Naseer AB, Raushid AS. 2018. Effect of guar gum conjugation on functional, antioxidant and antimicrobial activity of egg white lysozyme. Food Chem, 240: 1201-9.

Indrawati L, Zebin W, Ganesan N, Juan G. 2008. Effect of processing parameters on foam formation using a continuous system with a mechanical whipper. J Food Eng, 88(1): 65-74.

Kezwon A, Kamil W. 2014. Interaction of quillaja bark saponins with food-relevant proteins. Adv Colloid Interface Sci, 209: 185-95.

Kumar H, Alakesh M, Rajesh K. 2018. Modeling and desirability approach-based multi-response optimization of WEDM parameters in machining of aluminum metal matrix composite. J Braz Soc Mech Sci Eng, 40(9): 1-19.

Li H, Lijie C, Hongniao C, Ray KLS, Kequan Y. 2024. Environmental factors affecting accelerated carbonation of recycled concrete aggregates using response surface methodology. J Clean Prod, 474: 143599.

Li J, Jinjing S, Cuihua C, Luping G, Yujie S, Jiali Z, Yanjun Y. 2023. Influence of selected gums on the foaming properties of egg white powders: kinetics of foam formation and baking performance. Food Hydrocoll, 139: 108529.

Liszka-Skoczylas M, Anna P, Daniel Z. 2014. The effect of hydrocolloids on producing stable foams based on the whey protein concentrate (WPC). J Food Eng, 129: 1-11.

Malghan RL, Karthik MCR, Arun KS, Shrikantha SR, D'Souza RJ. 2017. Application of particle swarm optimization and response surface methodology for machining parameters optimization of aluminium matrix composites in milling operation. J Braz Soc Mech Sci Eng, 39(9): 3541-53.

Ptaszek P, Daniel Z, Joanna K, Kacper K, Wojciech R, Wiktor B. 2014. The physical and linear viscoelastic properties of fresh wet foams based on egg white proteins and selected hydrocolloids. Food Biophys, 9(1): 76-87.

Rawat N, Parvez A, Aman KB, Serges BLN, Tushar A, Raj KS, Neeraj A. 2024. Valorization of used cooking oil into bio-based surfactant: modeling and optimization using response surface methodology. Biomass Convers Biorefinery, 5: 1-14. https://doi.org/10.1007/s13399-024-05753-5

Sadahira M S, Maria I R, Mahmood A, Brent S M, Flavia M N. 2018. Influence of pH on foaming and rheological properties of aerated high sugar system with egg white protein and hydroxypropylmethylcellulose. LWT, 89: 350-57.

Tan, M. C., N. L. Chin, Y. A. Yusof, F. S. Taip, J. Abdullah. 2015. Characterisation of improved foam aeration and rheological properties of ultrasonically treated whey protein suspension. Int Dairy J, 43: 7-14.

Tang, T. Wu, S. Tang, S. Xiao, N. Wu, L. Tu, Y. Xu, M. 2022. Effect of modified egg white powder on the properties of angel cakes. J Food Eng, 326: 111012.

Wang Z, Sha Z, Bongkosh V. 2015. Foaming properties of whey protein isolate and λ-carrageenan mixed systems. J Food Sci, 80(8): N1893-1902.

Wojciechowski K, Aleksandra K, Joanna L, Kuba M. 2014. Effect of β-casein on surface activity of quillaja bark saponin at fluid/fluid interfaces. Food Hydrocoll, 34: 208-16.

Black Sea Journal of Agriculture
doi: 10.47115/bsagriculture.1608037

Open Access Journal
e-ISSN: 2618 – 6578

Research Article
Volume 8 - Issue 2 : 225-233 / March 2025

ENHANCING CADMIUM TOLERANCE IN COMMON BEAN PLANTS BY SEED PRIMING WITH PUTRESCINE

Hilal YILMAZ[1,2]* Vahdettin ÇİFTÇİ[2]

[1]*Kocaeli University, Izmit Vocational School, Department of Plant and Animal Production, 41285, Kocaeli, Türkiye*
[2]*Bolu Abant Izzet Baysal University, Faculty of Agriculture, Department of Field Crops, 14030, Bolu, Türkiye*

Abstract: This study evaluates the efficacy of putrescine-based seed biopriming at concentrations of 0, 0.25, 0.5, and 1 mmol in mitigating oxidative stress induced by 50 mg kg^{-1} cadmium (Cd) in common bean plants. Cadmium exposure significantly elevated oxidative stress markers, such as hydrogen peroxide (H_2O_2), while suppressing antioxidative enzyme activities, including ascorbate peroxidase (APX). Putrescine treatments, particularly at 0.5 and 1 mmol, enhanced antioxidative defenses by increasing superoxide dismutase (SOD) and APX activities and reducing H_2O_2 levels, thereby alleviating oxidative damage. Photosynthetic performance improved markedly with putrescine application, as evidenced by higher chlorophyll a content, an optimized chlorophyll a/b ratio, and increased total carotenoid levels, indicating enhanced photosynthetic efficiency under cadmium stress. Among the treatments, Cd-P3 (1 mmol putrescine) demonstrated the most significant improvements, reversing the detrimental effects of cadmium on photosynthetic pigments and plant health. Additionally, putrescine enhanced the accumulation of total phenolic and flavonoid compounds, contributing to improved antioxidant capacity. This was supported by higher DPPH radical scavenging activity and FRAP values, highlighting its strong antioxidative potential. In summary, putrescine seed priming offers a promising strategy for mitigating cadmium toxicity in plants. By modulating antioxidant systems, stabilizing photosynthetic pigments, and promoting bioactive compound synthesis, putrescine enhances plant resilience to heavy metal stress. These findings underscore its potential application in agricultural practices to improve crop tolerance to abiotic stresses.

Keywords: Putrescine seed priming, Cadmium stress mitigation, Antioxidant enzyme activity, Photosynthetic pigments, Heavy metal stress tolerance

***Corresponding author:** Kocaeli University, Izmit Vocational School, Department of Plant and Animal Production, 41285, Kocaeli, Türkiye
E mail: hilalayhanyilmaz@gmail.com (H. YILMAZ)
Hilal YILMAZ https://orcid.org/0000-0001-9138-3382
Vahdettin ÇİFTÇİ https://orcid.org/0000-0002-0440-5959
Received: December 27, 2024
Accepted: February 04, 2025
Published: March 15, 2025
Cite as: Yılmaz H, Çiftçi V. 2025. Enhancing cadmium tolerance in common bean plants by seed priming with putrescine. BSJ Agri, 8(2): 225-233.

1. Introduction

Modern agriculture is facing significant transformations driven by escalating environmental challenges, further intensified by the rapid growth of the global population (Yilmaz et al., 2024). The Green Revolution, while significantly enhancing agricultural productivity, has also led to unintended environmental consequences, including soil degradation and pollution of soil and water resources due to the excessive use of chemical inputs (Yilmaz and Yilmaz, 2025). A critical outcome of this intensive chemical use is the accumulation of heavy metals in agricultural soils. Soil contamination with heavy metals significantly disrupts ecosystems and poses severe risks to human health by compromising food quality, reducing arable land, and enabling the transfer of toxic elements through direct soil contact, polluted water, and the food chain (Haider et al., 2021). Among these contaminants, cadmium (Cd) is particularly concerning due to its high toxicity and environmental persistence. The primary sources of cadmium contamination in agricultural soils include industrial emissions, the application of cadmium-containing fertilizers, and the use of wastewater for irrigation (Lemessa et al., 2022). Although cadmium serves no biological purpose, its presence is highly detrimental to both plant and animal systems (Genchi et al., 2020). This metal is predominantly associated with industrial processes and phosphate-based fertilizers (Gupta et al., 2014). While cadmium is relatively rare in the Earth's crust, with an average concentration of approximately 0.2 mg kg^{-1}, it often co-occurs with zinc, lead, and copper sulfide ores (Kubier et al., 2019; Genchi et al., 2020). Its behavior and distribution in soils are influenced by several factors, including pH, clay content, soluble organic matter, and the presence of organic and inorganic ligands (Hamid et al., 2020).

Cadmium toxicity exerts multi-dimensional impacts on plants, affecting morphological, physiological, biochemical, and molecular processes (Farid et al., 2013). It disrupts essential metabolic activities such as photosynthesis and respiration, resulting in reduced root activity, stunted seedling growth, chlorosis, and ultimately plant death (Li et al., 2024; Ningombam et al., 2024). The physiological disorders caused by cadmium toxicity are closely linked to oxidative stress, driven by excessive reactive oxygen species (ROS) production (El

Rasafi et al., 2022). To counter these effects, plants have evolved various defense mechanisms, enabling survival in cadmium-contaminated soils (Raza et al., 2020; Canal et al., 2022; Canal et al., 2023). These mechanisms can be broadly classified into two strategies: reducing metal uptake to minimize toxicity and enhancing tolerance through the accumulation, storage, or immobilization of harmful elements within specific tissues (Kushwaha et al., 2015; Sarwar et al., 2017).

Recent advancements in stress management emphasize the efficacy of seed biopriming, wherein seeds are treated with beneficial agents to enhance resilience to abiotic stresses. Among these agents, putrescine, a polyamine, has shown promising potential in mitigating cadmium toxicity in various plants, including *Coriandrum sativum*, *Triticum aestivum*, *Camelina sativa*, and *Brassica napus*. Studies indicate that putrescine enhances antioxidant enzyme activity, promotes nutrient uptake, and supports plant health under heavy metal stress conditions (Tajti et al., 2018; Jahan et al., 2021; Sardar et al., 2022). As a critical polyamine, putrescine regulates plant growth and development by influencing key processes such as root elongation, flowering, fruit maturation, and stress responses (González-Hernández et al., 2022). Additionally, it functions as a signaling molecule and modulator of phytohormonal pathways, improving stress tolerance by regulating ROS levels, maintaining ion homeostasis, and interacting with hormones like abscisic acid (ABA), salicylic acid (SA), and indole-3-acetic acid (IAA) (Hussain et al., 2011; Liu et al., 2015; Mustafavi et al., 2018).

The common bean (*Phaseolus vulgaris* L.) is a nutritionally rich legume crop widely cultivated across diverse agro-climatic regions (Yılmaz et al., 2023). Renowned for its high protein, vitamin, and mineral content, it serves as a staple food in many parts of the world (Yılmaz, 2024). Despite its agricultural and economic importance, the common bean is highly sensitive to abiotic stresses, including heavy metal toxicity, which significantly impacts its growth, yield, and quality (Lone et al., 2021).

This study investigates the potential of putrescine-based seed biopriming to mitigate cadmium-induced stress in common bean plants subjected to 50 mg kg^{-1} of Cd. Seed treatments with putrescine at concentrations of 0, 0.25, 0.5, and 1 mmol were evaluated for their effects on oxidative stress markers, including malondialdehyde (MDA), antioxidant enzymes such as ascorbate peroxidase (APX) and superoxide dismutase (SOD), and photosynthetic pigments. The analyzed pigments included chlorophyll a, chlorophyll b, total chlorophyll, total carotenoids, and the chlorophyll a/b ratio. This is the first research to thoroughly investigate its effects on oxidative stress, antioxidant enzyme activity, and photosynthetic performance in common bean plants under cadmium stress.

2. Materials and Methods

2.1. Plant Material

The study was conducted using the dwarf common bean variety "Alberto," obtained from Harmas Global Agriculture and Industry Inc. The experiment took place under controlled environmental conditions in a climate chamber at the Faculty of Agriculture, Bolu Abant İzzet Baysal University, during November and December 2024. The climate chamber was maintained at a constant temperature of 24 °C with 70% relative humidity, and the plants were grown under a 16-hour light/8-hour dark photoperiod, ensuring optimal conditions for the study.

2.2. Experimental Design

Each pot, with a capacity of 1.5 kg, was filled with a substrate composed of two-thirds soil and one-third peat. Before sowing, cadmium was introduced into the soil at a concentration of 50 mg kg^{-1}. The seeds underwent surface sterilization by immersion in a 4% sodium hypochlorite solution for 5 minutes, followed by thorough rinsing with distilled water (4–5 times). After sterilization, the seeds were subjected to putrescine treatments at four different concentrations (0, 0.25, 0.5, and 1 mmol) by soaking them in the respective solutions at room temperature for 12 hours (Hussein et al., 2023). Following the biopriming procedure, three seeds were sown per pot. The plants were cultivated for three weeks under a randomized plot design with three replications. At the end of the growth period, leaf samples were collected and promptly stored at -80°C for subsequent analyses

2.3. Chlorophyll, and Carotenoid Contents

Total chlorophyll, carotenoid content, and chlorophyll a and b levels were assessed using the method described by Arnon (1949). For the chlorophyll analysis, 0.1 g of fresh leaf tissue was ground in 80% acetone, and the absorbance was measured at wavelengths of 663 nm, 645 nm, and 470 nm with a UV-visible spectrophotometer. Carotenoid analysis involved homogenizing 100 mg of leaf tissue in 80% (v/v) acetone, followed by filtration through filter paper, and measuring the absorbance of the filtrate at 470 nm. The concentrations of chlorophyll a, chlorophyll b, total chlorophyll, and carotenoids were determined in milligrams per gram of fresh weight (mg g^{-1} FW) using the following equations (1, 2, 3 and 4).

$$\text{Carotenoid (mg g}^{-1}\text{)} = [((1000 \times A470) - (2.27 \times Chla) - (81.4 \times Chlb)) / 227] \times V / g \quad (1)$$

$$\text{Chlorophyll a (mg g}^{-1}\text{ F.W.)} = (12.7 \times A663 - 2.69 \times A645) \times V / 1000 \times g \quad (2)$$

$$\text{Chlorophyll b (mg g}^{-1}\text{ F.W.)} = (22.9 \times A645 - 4.68 \times A663) \times V / 1000 \times g \quad (3)$$

$$\text{Total chlorophyll (mg g}^{-1}\text{ F.W.)} = (20.2 \times A645 + 8.02 \times A663) \times V / 1000 \times g \quad (4)$$

In these formulas, V; represents the volume of the extract, g is the weight of the sample, Chla; denotes chlorophyll a, Chlb; indicates chlorophyll b, and A refers to absorbance at the specified wavelengths.

2.4. Hydrogen Peroxide (H_2O_2) Analysis

Hydrogen peroxide (H_2O_2) levels were quantified spectrophotometrically based on its reaction with potassium iodide (KI) as described by Alexieva et al. (2001). For this analysis, 500 mg of leaf tissue was homogenized in 2.5 mL of 0.1% trichloroacetic acid (TCA) and centrifuged at 12.000×g for 15 minutes. The reaction mixture was prepared by combining 0.5 mL of the resulting supernatant with 0.5 mL of 100 mM potassium phosphate buffer (pH 7.0) and 2 mL of 1 M KI reagent. After incubation in the dark for 1 hour, absorbance was recorded at 390 nm. The hydrogen peroxide concentration was determined using a standard curve generated from serial dilutions of H_2O_2 solutions (100 µM).

2.5. Ascorbate Peroxidase (APX) and Superoxide Dismutase (SOD) Analysis

Ascorbate peroxidase (APX) activity was analyzed by monitoring the reduction in absorbance at 290 nm. Samples (200 mg) were homogenized in 2 mL of an extraction buffer containing sodium phosphate, sodium EDTA, and ascorbic acid, followed by centrifugation at 15.000 rpm. The reaction mixture included sodium phosphate buffer (pH 7.0), ascorbic acid, and EDTA, to which 0.1 mL of the sample extract and 0.1 mL of H_2O_2 were added. Activity was determined using an ascorbic acid standard curve (Yilmaz and Kulaz, 2019). Superoxide dismutase (SOD) activity was assessed by evaluating its capacity to inhibit the reduction of nitro blue tetrazolium (NBT). Homogenized samples (200 mg) in a buffer containing sodium phosphate and EDTA were centrifuged at 15.000 rpm. The reaction mixture included methionine, NBT, EDTA, sodium phosphate, sodium carbonate, and riboflavin. Following light exposure (75 $\mu mol\ m^{-2}\ s^{-1}$) for 15 minutes, absorbance at 560 nm was used to calculate SOD activity based on the degree of NBT photochemical reduction inhibition (Beauchamp and Fridovich, 1971).

2.6 Antioxidant Assays for Phenolic, Flavonoid Content, and Antioxidant Activity

The total phenolic content was determined using a modified microscale approach as described by Waterhouse (2002). The assay involved mixing the sample with Folin-Ciocalteu reagent and sodium carbonate, followed by incubation in the dark for two hours. Absorbance was then measured at 760 nm using a spectrophotometer. Gallic acid served as the standard, and the results were expressed in mg/g gallic acid equivalents (GAE). The total flavonoid content was determined using a modified method adapted from Feduraev et al. (2022). Plant extracts or standard solutions were reacted sequentially with sodium nitrite, aluminum chloride, and sodium hydroxide, followed by dilution to the final volume. Absorbance was recorded at 430 nm, with quercetin as the standard, and the results were expressed in mM. The antioxidant capacity was evaluated using the DPPH (2,2-diphenyl-1-picrylhydrazyl) radical scavenging assay based on the method by Ünal and Okatan, (2023). Samples were mixed with DPPH in ethanol, and absorbance was measured at 517 nm after 15 minutes of reaction time. Ascorbic acid was employed as the standard to calculate scavenging activity, and the EC_{50} value, indicating the concentration required to achieve a 50% reduction in DPPH radicals, was expressed in mg mL^{-1}.

The ferric reducing antioxidant power (FRAP) assay was performed following the protocol of Benzie and Strain (1996). The samples and standards were reacted with a FRAP reagent diluted 1:1, and absorbance was recorded at the specified wavelength. L-ascorbic acid was used as the standard, and the results were reported in mM.

2.7. Statistical Analysis

The experiment was designed as a randomized plot layout, incorporating three biological replicates and three technical replicates for each treatment. To assess the impact of cadmium stress and the applied treatments, a one-way analysis of variance (ANOVA) was performed. Pairwise comparisons between the control group and the treatments were conducted using Duncan's Multiple Range Test. Correlation analyses were conducted to explore the relationships between yield parameters and antioxidant enzyme activities under water stress, using Pearson's coefficient. Data were visualized with the 'corrplot' R package (Wei et al., 2017).

3. Results and Discussion

3.1. Plant Defense Mechanisms in Response to Cadmium Stress

The statistical analysis results revealed that the treatments, including different doses of putrescine (0, 0.25, 0.5, and 1 mmol) and cadmium (50 ppm), had a highly significant effect on the measured parameters, including SOD (superoxide dismutase) activity, hydrogen peroxide (H_2O_2) content, APX (ascorbate peroxidase) activity, chlorophyll a, chlorophyll b, chlorophyll a/b, total chlorophyll, total carotenoid content, total phenolic content (TPC), total flavonoid content (TFC), DPPH radical scavenging activity, FRAP antioxidant capacity, and CUPRAC antioxidant capacity, with an F-value indicating statistical significance at $p < 0.001$ (Table 1, Figure 1).

Table 1. ANOVA table showing the minimum, maximum, mean, standard error, F-value, and %CV for rhizobacterial applications in common bean

Variables	Min.	Max.	Mean	Std. Error	F value
SOD	70.42	220.97	138.09	6.97	33.64***
H_2O_2	1094	2464.2	1704.9	83.91	249.26***
APX	0.27	1.27	0.71	0.06	187.53***
Chlo a	0.01	0.03	0.016	0.001	121.22***
Chlo b	0.004	0.02	0.010	0.001	164.97***
Chlo a/b	0.31	5.04	2.24	0.29	369.27***
TChlo	0.019	0.03	0.026	0.001	30.01***
TCar	125.0	244.94	197.84	6.89	203.72***
TPC	6.44	15.14	11.17	0.47	199.04***
TFC	2.45	6.92	4.84	0.24	46.02***
DPPH	21.3	66.85	43.82	2.63	198.76***
FRAP	15.11	45.54	31.93	1.81	89.51***

Significant differences according to Duncan test; *** (P≤0.001)

The Cd treatment (121.07 U g^{-1} FW) increased SOD activity by 46.6% compared to the control (82.60 U g^{-1} FW), highlighting oxidative stress induced by cadmium. Among the putrescine treatments, P3 (166.75 U g^{-1} FW) was the most effective, showing a 102% increase compared to the control. Against cadmium alone, Cd-P3 (197.39 U g^{-1} FW) further enhanced SOD activity by 63%, demonstrating its superior ability to mitigate oxidative stress.

Cadmium application significantly increased H_2O_2 levels (2444.60 μmol g^{-1} FW), a 24% rise compared to the control (1965.50 μmol g^{-1} FW). In contrast, putrescine treatments reduced H_2O_2 levels, with P3 (1133.70 μmol g^{-1} FW) achieving the greatest reduction (42%). Among cadmium-treated groups, Cd-P3 (1615.00 μmol g^{-1} FW) reduced H_2O_2 by 34%, confirming the effectiveness of putrescine in mitigating oxidative damage.

APX activity was highest in the control group (1.26 mM g FW min^{-1}). Cadmium alone caused a 75% reduction, indicating severe oxidative stress. Putrescine treatments significantly restored APX activity, with P1 (1.01 mM g FW min^{-1}) showing the strongest protection (only 20% reduction). Cd-P3 (0.99 mM g FW min^{-1}) exhibited a 219% improvement over cadmium alone, highlighting its remarkable protective effect. Overall, Cd-P3 consistently demonstrated superior performance in mitigating cadmium-induced oxidative stress.

The highest chlorophyll a content was recorded in the P3 treatment (0.024 mg g^{-1} FW), followed by Cd-P3 (0.021 mg g^{-1} FW). Cadmium alone (Cd, 0.007 mg g^{-1} FW) resulted in the lowest chlorophyll a level, showing a significant decline compared to the control (0.013 mg g^{-1} FW). Among cadmium treatments, Cd-P3 demonstrated the most effective mitigation, with a 200% increase in chlorophyll a content compared to cadmium alone.

Interestingly, chlorophyll b content was highest in the Cd treatment (0.021 mg g^{-1} FW), reflecting stress-induced chlorophyll accumulation. Among cadmium + putrescine treatments, Cd-P1 (0.014 mg g^{-1} FW) showed the best mitigation effect, followed by Cd-P2 (0.013 mg g^{-1} FW) and Cd-P3 (0.010 mg g^{-1} FW). In contrast, the lowest chlorophyll b content was recorded in the P3 treatment (0.004 mg g^{-1} FW), indicating that putrescine alone without cadmium has limited impact on chlorophyll b levels.

The chlorophyll a/b ratio, an indicator of photosynthetic efficiency, was highest in the P3 treatment (4.92), followed by P2 (3.67) and P1 (2.97), demonstrating the enhancing effect of putrescine alone. Among cadmium treatments, Cd-P3 (2.09) showed the greatest improvement compared to cadmium alone (0.34), highlighting putrescine's role in alleviating the negative effects of cadmium stress on the chlorophyll a/b balance.

The highest total chlorophyll content was observed in the Cd-P3 treatment (0.031 mg g^{-1} FW), followed by Cd-P2 (0.030 mg g^{-1} FW) and P3 (0.029 mg g^{-1} FW). Cadmium alone (Cd, 0.028 mg g^{-1} FW) exhibited slightly higher levels than the control (C, 0.022 mg g^{-1} FW), likely due to stress-induced chlorophyll changes. Among all treatments, Cd-P3 was the most effective in enhancing total chlorophyll content, suggesting that putrescine applications, particularly at higher doses, mitigate cadmium stress and support chlorophyll synthesis.

For total carotenoids, the highest content was recorded in the Cd-P3 treatment (239.36 mg g^{-1} FW), followed by Cd-P2 (222.85 mg g^{-1} FW) and Cd-P1 (213.57 mg g^{-1} FW), demonstrating the effectiveness of putrescine in mitigating cadmium stress. Cadmium alone (Cd, 168.08 mg g^{-1} FW) showed a significant reduction compared to the control (C, 127.68 mg g^{-1} FW), reflecting the oxidative damage caused by cadmium. Among treatments without cadmium, P3 (211.52 mg g^{-1} FW) exhibited the highest carotenoid content, highlighting its protective role. Overall, Cd-P3 provided the most substantial enhancement of carotenoid content, effectively reducing cadmium-induced oxidative stress and supporting antioxidant capacity.

The highest total phenolic content (TPC) was observed in the Cd-P3 treatment (14.67 mg mL^{-1} GAE eq), followed by Cd-P2 (12.77 mg mL^{-1} GAE eq) and Cd-P1 (12.36 mg mL^{-1} GAE eq), underscoring the ameliorative effect of putrescine under cadmium stress. Cadmium alone (Cd, 10.25 mg mL^{-1} GAE eq) caused an increase compared to the control (C, 6.62 mg mL^{-1} GAE eq), indicating stress-induced phenolic accumulation. Among treatments without cadmium, P3 (11.70 mg mL^{-1} GAE eq) showed the highest TPC. Overall, Cd-P3 demonstrated the greatest improvement, highlighting its role in enhancing phenolic content and alleviating oxidative stress caused by cadmium.

For total flavonoid content (TFC), the highest level was recorded in the Cd-P3 treatment (6.69 mg mL^{-1} QE eq), followed by Cd-P2 (5.74 mg mL^{-1} QE eq), demonstrating putrescine's effectiveness in mitigating cadmium stress. Among treatments without cadmium, P3 (5.23 mg mL^{-1} QE eq) showed the highest TFC. Cadmium alone (Cd, 3.91 mg mL^{-1} QE eq) resulted in a moderate increase compared to the control (C, 2.75 mg mL^{-1} QE eq), reflecting stress-induced flavonoid synthesis. Cd-P3 provided the most significant enhancement, emphasizing its strong role in reducing oxidative stress and promoting flavonoid accumulation.

The highest DPPH radical scavenging activity was observed in the P3 treatment (65.01 mg mL^{-1} ASA eq), followed by Cd-P3 (57.14 mg mL^{-1} ASA eq), reflecting the potent antioxidant effect of putrescine, particularly in the absence of cadmium. Among cadmium treatments, Cd-P3 showed the greatest improvement, with a 64% increase in antioxidant activity compared to cadmium alone (34.81 mg mL^{-1} ASA eq). The control group (C, 22.02 mg mL^{-1} ASA eq) exhibited the lowest activity, underscoring the stress-induced increase in antioxidant capacity due to cadmium and putrescine treatments. Overall, P3 and Cd-P3 significantly enhanced the antioxidant defense system, highlighting their effectiveness in alleviating cadmium-induced oxidative stress.

The highest FRAP value was recorded in the P3 treatment (45.04 mg mL^{-1} ASA eq), followed by Cd-P3 (40.19 mg mL^{-1} ASA eq), highlighting the strong antioxidant potential of putrescine, both in the presence and absence of cadmium. Among cadmium treatments, Cd-P3 demonstrated a significant improvement, with a 59% increase in FRAP activity compared to cadmium alone (25.36 mg mL^{-1} ASA eq). The control group (C, 15.52 mg mL^{-1} ASA eq) showed the lowest antioxidant capacity, reflecting the stress-induced enhancement achieved through cadmium and putrescine treatments. Overall, P3 and Cd-P3 were the most effective in enhancing antioxidant activity.

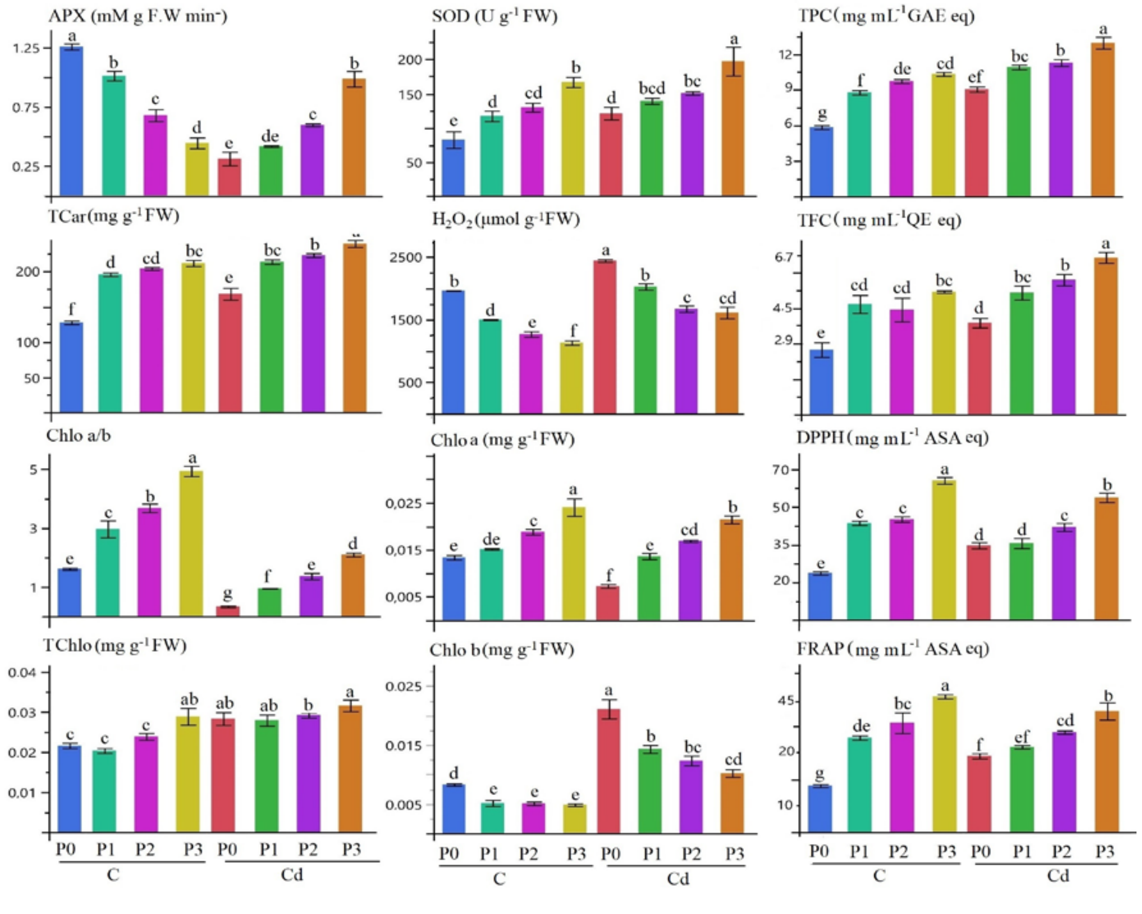

Figure 1. Effects of putrescine (0, 0.25, 0.5, and 1.0 mmol) on chlorophyll a (Chlo a), chlorophyll b (Chlo b), chlorophyll a/b ratio (Chlo a/b), total chlorophyll (TChlo), total carotenoid content (TCar), ascorbate peroxidase activity (APX), superoxide dismutase activity (SOD), hydrogen peroxide content (H_2O_2), DPPH radical scavenging activity (DPPH), ferric reducing antioxidant power (FRAP), total phenolic content (TPC), and total flavonoid content (TFC) in common bean plants under cadmium stress (50 mg kg^{-1}) (C= control; Cd= cadmium).

3.2 Correlations Among Studied Characteristics

The correlation analysis revealed many significant relationships between physiological, biochemical, and antioxidative parameters (Figure 2). A strong negative correlation between hydrogen peroxide (H_2O_2) and antioxidant enzymes such as SOD (r= -0.40) and APX (r= -0.26) indicates that increased oxidative stress, marked by higher H_2O_2 levels, suppresses the enzymatic defense system. Conversely, positive correlations among chlorophyll pigments (CHL A, CHL B, and Total Chlorophyll) demonstrate the synchronized regulation of the photosynthetic apparatus under cadmium stress. The strong negative correlation of CHL A/B with H_2O_2 (r= -0.92) further emphasizes the detrimental effect of oxidative stress on the photosynthetic efficiency.

CUPRAC, a key measure of antioxidant capacity, exhibited robust positive correlations with TPC (r= 0.70), TFC (r= 0.72) and DPPH (r= 0.93) highlighting the critical role of phenolic and flavonoid compounds in scavenging reactive oxygen species (ROS) and mitigating oxidative damage. Similarly, FRAP (r= 0.92) showed strong correlations with CUPRAC, underscoring the complementary nature of these antioxidant capacity assays. These findings collectively emphasize the pivotal role of antioxidant systems in protecting chlorophyll content, enhancing carotenoid levels, and reducing oxidative stress caused by cadmium toxicity. Overall, the results underscore the intricate interplay between antioxidative defenses, photosynthetic pigments, and bioactive compounds in alleviating cadmium-induced oxidative damage, providing insights into potential mechanisms underlying plant resilience under heavy metal stress.

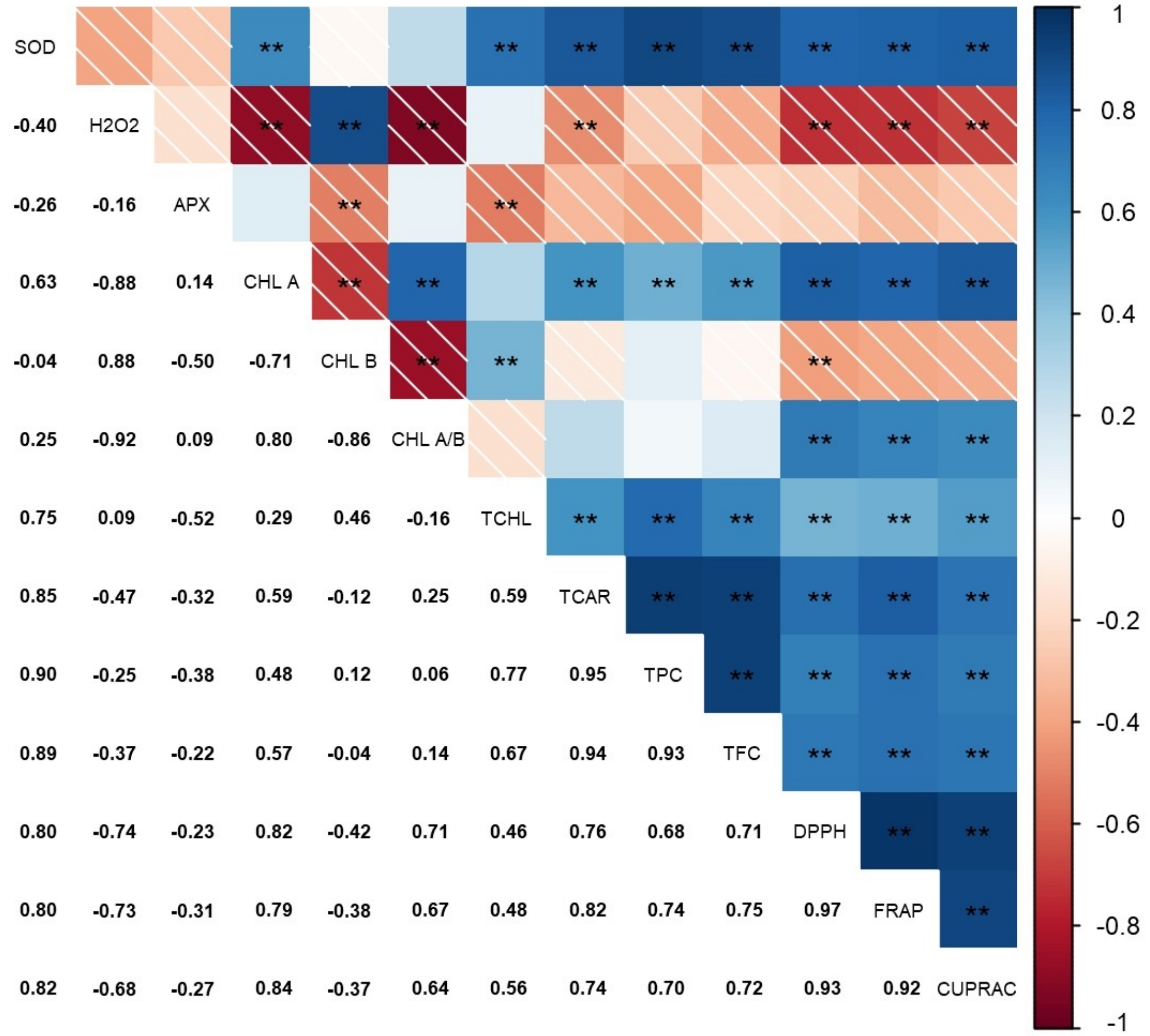

Figure 2. Correlations between the studied characteristics in common bean. *, and ** indicates significance at p≤0.05, p≤0.01, respectively (SOD= superoxide dismutase activity, H_2O_2= hydrogen peroxide, APX= ascorbate peroxidase activity, CHL A= chlorophyll a, CHL B= chlorophyll b, CHL A/B= chlorophyll a/b ratio, TCHL= total chlorophyll, TCar= total carotenoid content, TPC= total phenolic content, TFC= total flavonoid content, DPPH= DPPH radical scavenging activity, FRAP= ferric reducing antioxidant power, CUPRAC= cupric reducing antioxidant capacity).

4. Discussion

This study demonstrates the protective role of putrescine in mitigating cadmium (Cd)-induced oxidative stress in common bean plants. The findings reveal significant improvements in antioxidative enzyme activities, reductions in oxidative damage markers, and enhancements in photosynthetic pigments and antioxidant compounds under putrescine treatments, particularly at higher doses. These results align with previous studies highlight the efficacy of polyamines, such as putrescine, in alleviating heavy metal stress. Putrescine, a type of polyamine, has been widely recognized for its essential role in enhancing plant resilience against various abiotic stresses, including cadmium toxicity (González-Hernández et al., 2022). Cadmium is a heavy metal that induces oxidative stress in plants, leading to the excessive generation of reactive oxygen species (ROS) and subsequent cellular damage (Mansoor et al., 2023). The adverse effects of cadmium exposure are primarily attributed to increased hydrogen peroxide levels and lipid peroxidation, which significantly impair plant growth and physiological functions. To counteract these effects, plants activate their antioxidant defense systems, which are crucial for detoxifying ROS and preserving cellular integrity (Kumar and Pathak, 2018; Muneer et al., 2012). The application of putrescine has been shown to enhance the antioxidative metabolism of plants, thereby mitigating cadmium-induced damage. For instance, exogenous putrescine alleviated cadmium stress in coriander by enhancing antioxidant enzyme activity, improving photosynthesis and growth, and reducing oxidative damage markers such as malondialdehyde (MDA) (Sardar et al., 2022). In rice, putrescine pre-treatment enhanced cadmium resistance by increasing root cell wall hemicellulose levels to bind more Cd, regulating key Cd transport genes to limit Cd absorption, promoting vacuolar sequestration, and stimulating nitric oxide (NO) generation, a signaling molecule crucial for stress tolerance.

Additionally, putrescine is known to induce the synthesis of phytochelatins—peptides that chelate heavy metals—thereby facilitating their detoxification (Pál et al., 2017). It also significantly increases the activity of key antioxidant enzymes, such as superoxide dismutase (SOD) and peroxidase (POD), which play pivotal roles in scavenging ROS and protecting plant cells from oxidative damage (Tajti et al., 2018). The enhancement of these enzymatic activities is often linked to the upregulation of genes involved in antioxidant defense pathways, suggesting that putrescine not only acts as a direct protective agent but also modulates gene expression related to stress responses (Mohammadi-Cheraghabadi et al., 2021). Moreover, putrescine has demonstrated efficacy in improving plant growth and physiological responses under cadmium stress. Research indicates that cadmium exposure results in a significant decline in chlorophyll content, often accompanied by leaf chlorosis (Zhao et al., 2021). This reduction in chlorophyll levels is attributed to cadmium's inhibitory effects on pigment biosynthesis enzymes and its interference with the electron transport chain within chloroplasts (Muradoglu et al., 2015). Pre-treatment with putrescine has been shown to alleviate these adverse effects, restoring chlorophyll content and promoting plant biomass, thereby supporting overall plant health (Tajti et al., 2018; Badihi et al., 2021; Hussein et al., 2023). This protective effect is primarily attributed to putrescine's ability to stabilize cell membranes and enhance photosynthetic efficiency, which is critical for maintaining energy balance under stress conditions (Gupta et al., 2012). Furthermore, putrescine application has been associated with improved water retention and nutrient uptake, further contributing to enhanced plant resilience against heavy metal toxicity (Mohammadi-Cheraghabadi et al., 2021). The antioxidant capacity of putrescine can be effectively assessed using various assays, such as TPC, TFC, and antioxidant assays like CUPRAC, FRAP, and DPPH. These assays evaluate the ability of putrescine-treated plants to neutralize free radicals, providing insights into their potential protective effects against oxidative stress (Tumilaar et al., 2024). Studies have consistently shown that putrescine treatment increases TPC and TFC levels, which correlate with enhanced antioxidant activity measured through assays such as CUPRAC and DPPH (Gul et al., 2018; Zeynali et al., 2023; Hussein et al., 2023). In summary, putrescine acts as a multifaceted stress mitigator by modulating antioxidant systems, stabilizing cellular structures, and improving physiological responses. These findings underscore its potential as a practical and sustainable strategy for enhancing plant tolerance to cadmium stress and other abiotic challenges.

5. Conclusion

This study highlights the efficacy of putrescine, applied as seed priming, in mitigating cadmium-induced stress in plants. The findings demonstrate that putrescine significantly enhances antioxidative enzyme activities, stabilizes photosynthetic pigments, reduces hydrogen peroxide (H_2O_2) accumulation, and promotes the synthesis of antioxidant compounds under cadmium stress conditions. These results underscore its potential as a practical and sustainable strategy for improving plant resilience to heavy metal toxicity. Future research should focus on elucidating the molecular mechanisms underlying these effects and assessing the long-term applicability of putrescine seed priming across diverse crop species under field conditions.

Author Contributions

The percentages of the authors' contributions are presented below. All authors reviewed and approved the final version of the manuscript.

	H.Y.	V.Ç.
C	50	50
D	100	
S		100
DCP	100	
DAI	100	
L	100	
W	100	
CR		100
SR	50	50
PM		100
FA		100

C= concept, D= design, S= supervision, DCP= data collection and/or processing, DAI= data analysis and/or interpretation, L= literature search, W= writing, CR= critical review, SR= submission and revision, PM= project management, FA= funding acquisition.

Conflict of Interest

The authors declared that there is no conflict of interest.

Ethical Consideration

Ethics committee approval was not required for this study because there was no study on animals or humans.

Acknowledgments

We would like to express our heartfelt appreciation to Assoc. Prof. Dr. Emrah GÜLER for his invaluable support in the analysis of bioactive components during this study.

References

Alexieva V, Sergiev I, Mapelli S, Karanov E. 2001. The effect of drought and ultraviolet radiation on growth and stress markers in pea and wheat. Plant Cell Environ, 24(12): 1337-1344.

Arnon DI. 1949. Copper enzymes in isolated chloroplasts. Polyphenoloxidase in *Beta vulgaris*. Plant Physiol, 24(1): 1.

Badihi L, Gerami M, Akbarinodeh D, Shokrzadeh M, Ramezani M. 2021. Physio-chemical responses of exogenous calcium nanoparticle and putrescine polyamine in Saffron (*Crocus sativus* L.). Physiol Mol Biol Plants, 27: 119-133.

Beauchamp C, Fridovich I. 1971. Superoxide dismutase: improved assays and an assay applicable to acrylamide gels. Anal Biochem, 44(1): 276-287.

Benzie IF, Strain JJ. 1996. The ferric reducing ability of plasma (FRAP) as a measure of "antioxidant power": the FRAP assay. Anal Biochem, 239(1): 70-76.

Canal SB, Bozkurt MA, Yilmaz H. 2022. Effects of humic acid and edta on phytoremediation, growth and antioxidant activity in rapeseed (*Brassica napus* L.) Grown under Heavy Metal Stress. Polish J Environ Stud, 31(5).

Canal SB, Bozkurt MA, Yílmaz H. 2023. Humic acid ameliorates phytoremediation, plant growth and antioxidative enzymes in forage turnip (*Brassica rapa* L.). Plant Soil Env, 69(12).

El Rasafi T, Oukarroum A, Haddioui A, Song H, Kwon EE, Bolan N, Rinklebe J. 2022. Cadmium stress in plants: a critical review of the effects, mechanisms, and tolerance strategies. Crit Rev Environ Sci Technol, 52(5): 675-726.

Farid M, Shakoor MB, Ehsan S, Ali S, Zubair M, Hanif MS. 2013. Morphological, physiological and biochemical responses of different plant species to Cd stress. Int J Chem Biochem Sci, 3: 53-60.

Feduraev P, Skrypnik L, Nebreeva S, Dzhobadze G, Vatagina A, Kalinina E, Chupakhina G. 2022. Variability of phenolic compound accumulation and antioxidant activity in wild plants of some Rumex species (Polygonaceae). Antioxidants, 11(2): 311.

Genchi G, Sinicropi MS, Lauria G, Carocci A, Catalano A. 2020. The effects of cadmium toxicity. Int J Environ Res Public Health, 17(11): 3782.

González-Hernández AI, Scalschi L, Vicedo B, Marcos-Barbero EL, Morcuende R, Camañes G. 2022. Putrescine: a key metabolite involved in plant development, tolerance and resistance responses to stress. Int J Mol Sci, 23(6): 2971.

Gul H, Anjum L, Arif M, Shah M. 2018. Effects of exogeneous application of putrescine on different biochemical parameters of *Zea mays* L. under salinity stress. FUUAST J Biol, 8(1): 65-72.

Gupta DK, Chatterjee S, Datta S, Veer V, Walther C. 2014. Role of phosphate fertilizers in heavy metal uptake and detoxification of toxic metals. Chemosphere, 108: 134-144.

Gupta S, Agarwal VP, Gupta NK. 2012. Efficacy of putrescine and benzyladenine on photosynthesis and productivity in relation to drought tolerance in wheat (*Triticum aestivum* L.). Physiol Mol Biol Plants, 18: 331-336.

Haider FU, Liqun C, Coulter JA, Cheema SA, Wu J, Zhang R, Farooq M. 2021. Cadmium toxicity in plants: ımpacts and remediation strategies. Ecotoxicol Environ Saf, 211: 111887.

Hamid Y, Tang L, Hussain B, Usman M, Lin Q, Rashid MS, Yang X. 2020. Organic soil additives for the remediation of cadmium contaminated soils and their impact on the soil-plant system: A review. Sci Total Environ, 707: 136121.

Hussain SS, Ali M, Ahmad M, Siddique KH. 2011. Polyamines: natural and engineered abiotic and biotic stress tolerance in plants. Biotechnol Adv, 29(3): 300-311.

Hussein HAA, Alshammari SO, Abd El-Sadek ME, Kenawy SK, Badawy AA. 2023. The promotive effect of putrescine on growth, biochemical constituents, and yield of wheat (*Triticum aestivum* L.) plants under water stress. Agric, 13(3): 587.

Jahan A, Iqbal M, Malik A. 2021. Individual rather than simultaneous priming with glutathione and putrescine reduces chromium Cr 6+ toxicity in contrasting canola (*Brassica napus* L.) cultivars. Bull Environ Contam Toxicol, 107: 427-432.

Kubier A, Wilkin RT, Pichler T. 2019. Cadmium in soils and groundwater: A review. Appl Geochem, 108: 104388.

Kumar P, Pathak S. 2018. Short-term response of plants grown under heavy metal toxicity. Heavy Metals, 69: 10-5772.

Kushwaha A, Rani R, Kumar S, Gautam A. 2015. Heavy metal detoxification and tolerance mechanisms in plants: Implications for phytoremediation. Environ Rev, 24(1): 39-51.

Lemessa F, Simane B, Seyoum A, Gebresenbet G. 2022. Analysis of the concentration of heavy metals in soil, vegetables and water around the Bole Lemi Industry Park, Ethiopia. Heliyon, 8(12): e123456.

Li C, Fu Y, Trotsenko V, Zhatova H. 2024. Understanding the physiological and molecular mechanisms of grain cadmium accumulation conduces to produce low cadmium grain crops: A review. Plant Growth Regul, 103(2): 257-269.

Liu JH, Wang W, Wu H, Gong X, Moriguchi T. 2015. Polyamines function in stress tolerance: from synthesis to regulation. Front Plant Sci, 6: 827.

Lone AA, Khan MN, Gul A, Dar ZA, Iqbal AM, Lone BA, Nisar F. 2021. Common beans and abiotic stress challenges. Curr J Appl Sci Technol, 40: 41-53.

Mansoor S, Ali A, Kour N, Bornhorst J, AlHarbi K, Rinklebe J, Chung YS. 2023. Heavy metal induced oxidative stress mitigation and ROS scavenging in plants. Plants, 12(16): 3003.

Mohammadi-Cheraghabadi M, Modarres-Sanavy SAM, Sefidkon F, Rashidi-Monfared S, Mokhtassi-Bidgoli A. 2021. Improving water deficit tolerance of *Salvia officinalis* L. using putrescine. Sci Rep, 11(1): 21997.

Muneer S, Kim TH, Qureshi MI. 2012. Fe modulates Cd-induced oxidative stress and the expression of stress responsive proteins in the nodules of *Vigna radiata.* Plant Growth Regul, 68: 421-433.

Muradoglu F, Gundogdu M, Ercisli S, Encu T, Balta F, Jaafar HZ, Zia-Ul-Haq M. 2015. Cadmium toxicity affects chlorophyll a and b content, antioxidant enzyme activities and mineral nutrient accumulation in strawberry. Biol Res, 48: 1-7.

Mustafavi SH, Naghdi Badi H, Sękara A, Mehrafarin A, Janda T, Ghorbanpour M, Rafiee H. 2018. Polyamines and their possible mechanisms involved in plant physiological processes and elicitation of secondary metabolites. Acta Physiol Plant, 40: 1-19.

Ningombam L, Hazarika BN, Yumkhaibam T, Heisnam P, Singh YD. 2024. Heavy metal priming plant stress tolerance deciphering through physiological, biochemical, molecular and omics mechanism. S Afr J Bot, 168: 16-25.

Pál M, Csávás G, Szalai G, Oláh T, Khalil R, Yordanova R, Janda T. 2017. Polyamines may influence phytochelatin synthesis during Cd stress in rice. J Hazard Mater, 340: 272-280.

Raza A, Habib M, Kakavand SN, Zahid Z, Zahra N, Sharif R, Hasanuzzaman M. 2020. Phytoremediation of cadmium: physiological, biochemical, and molecular mechanisms. Biol, 9(7): 177.

Sardar R, Ahmed S, Yasin NA. 2022. Role of exogenously applied putrescine in amelioration of cadmium stress in *Coriandrum sativum* by modulating antioxidant system. Int J Phytoremediation, 24(9): 955-962.

Sarwar N, Imran M, Shaheen MR, Ishaque W, Kamran MA, Matloob A, Hussain S. 2017. Phytoremediation strategies for soils contaminated with heavy metals: modifications and future perspectives. Chemosphere, 171: 710-721.

Tajti J, Janda T, Majláth I, Szalai G, Pál M. 2018. Comparative study on the effects of putrescine and spermidine pre-treatment on cadmium stress in wheat. Ecotoxicol Environ Saf, 148: 546-554.

Tumilaar SG, Hardianto A, Dohi H, Kurnia D. 2024. A comprehensive review of free radicals, oxidative stress, and antioxidants: Overview, clinical applications, global perspectives, future directions, and mechanisms of antioxidant activity of flavonoid compounds. J Chem, 2024(1): 5594386.

Ünal N, Okatan V. 2023. Effects of drought stress treatment on phytochemical contents of strawberry varieties. Sci Hortic, 316: 112013.

Waterhouse AL. 2002. Determination of total phenolics. Curr Protoc Food Anal Chem, 6(1): 1-8.

Wei T, Simko V, Levy M, Xie Y, Jin Y, Zemla J. 2017. Package 'corrplot'. Stat, 56: e24.

Yilmaz H, Kulaz H. 2019. The effects of plant growth promoting rhizobacteria on antioxidant activity in chickpea (*Cicer arietinum* L.) under salt stress. Legume Res Int J, 42(1): 72-76.

Yilmaz H, Özer G, Baloch FS, Çiftçi V, Chung YS, Sun HJ. 2023. Genome-wide identification and expression analysis of MTP (Metal ion transport proteins) genes in the common bean. Plants, 12(18): 3218.

Yılmaz H. 2024. Foliar application of ascorbic acid and green-synthesized nano iron for enhancing drought tolerance and antioxidant defense in common beans. BSJ Agric, 7(6): 766-776.

Yilmaz H, Yilmaz A. 2025. Hidden hunger in the age of abundance: the nutritional pitfalls of modern staple crops. Food Sci Nutr, 13: e4610.

Yilmaz H, Karatas R, Demirel F, Soysal S, Türkoğlu A, Yilmaz A, Ciftci V. 2024. Variations in protein, gluten, Zeleny sedimentation and yield of certain wheat (*Triticum aestivum* L.) cultivars under different climatic conditions. Euphytica, 220(12): 190.

Zeynali R, Najafian S, Hosseinifarahi M. 2023. Exogenous putrescine changes biochemical (antioxidant activity, polyphenol, flavonoid, and total phenol compounds) and essential oil constituents of *Salvia officinalis* L. Chem Biodiver, 20(11): e202301043.

Zhao H, Guan J, Liang Q, Zhang X, Hu H, Zhang J. 2021. Effects of cadmium stress on growth and physiological characteristics of sassafras seedlings. Sci Rep, 11(1): 9913.

Black Sea Journal of Agriculture
doi: 10.47115/bsagriculture.1616876

Open Access Journal
e-ISSN: 2618 – 6578

Research Article
Volume 8 - Issue 2 : 234-239 / March 2025

ASSESSMENT OF PASTURE NUTRITIONAL VALUE AND YIELD ON GİTO PLATEAU (ÇAMLIHEMŞİN, TÜRKİYE)

Muhammed İkbal ÇATAL[1]*

[1]*Recep Tayyip Erdoğan University, Faculty of Agriculture, Department of Field Crops, 53300, Rize, Türkiye.*

Abstract: This study investigated the nutritional value and yield of Gito Plateau pasture, located in the Çamlıhemşin district of Rize province, Türkiye, during the summers of 2023 and 2024. Plant samples from 12 different locations were collected and analyzed to determine their nutrient composition. The average dry matter yield was 114.12 kg/da. Crude protein content averaged 10.46%, with minimal inter-annual variation. Fiber analysis revealed average acid detergent fiber (ADF) and neutral detergent fiber (NDF) values of 37.44% and 69.10%, respectively, indicating moderate digestibility. Calculated feed quality parameters included digestible dry matter (DDM) of 59.73% and relative feed value (RFV) of 80.42. Mineral analysis showed average concentrations of phosphorus (0.24%), potassium (1.53%), calcium (1.13%), and magnesium (0.30%), with Ca/P and K/(Ca+Mg) ratios averaging 4.81 and 1.07, respectively. The relatively consistent nutrient composition across the two years suggests a stable forage resource. These findings provide baseline data on Gito Plateau's pasture nutritional value, informing sustainable grazing management practices and optimizing livestock production in the Eastern Black Sea Region of Türkiye. Further research is recommended to assess seasonal variations and the impact of grazing management on pasture quality.

Keywords: Gito Plateau, Rize, Forage quality, Nutrient composition

***Corresponding author:** Recep Tayyip Erdoğan University, Faculty of Agriculture, Department of Field Crops, 53300, Rize, Türkiye
E mail: muhammed.catal@erdogan.edu.tr (M.İ. ÇATAL)
Muhammed İkbal ÇATAL https://orcid.org/0000-0002-4888-770X

Received: January 09, 2025
Accepted: March 02, 2025
Published: March 15, 2025
Cite as: Çatal Mİ. 2025. Assessment of pasture nutritional value and yield on Gito Plateau (Çamlıhemşin, Türkiye). BSJ Agri, 8(2): 234-239.

1. Introduction

Feed costs represent a substantial expenditure in livestock production, making efficient feed utilization crucial. Pastures serve as the most economical source of roughage, underpinning sustainable livestock farming practices. Globally, approximately 70% of roughage consumed by livestock is derived from pastures (Lund, 2007). The increasing global population, coupled with the exacerbating effects of climate change and economic volatility, places increasing pressure on these ecosystems to provide high-quality roughage. However, the conversion of pasturelands to other land uses and the pervasive issue of overgrazing significantly threaten the productivity of these vital natural resources. Overgrazing is a primary driver of pasture degradation, particularly in arid and semi-arid regions (Snyman, 2005; Holechek et al., 2011). This degradation manifests in reduced pasture yields, deterioration of soil physical and chemical properties (Beukes and Cowling, 2003), and increased susceptibility to erosion. Moreover, overgrazing can facilitate the proliferation of undesirable plant species, reduce plant cover, and result in substantial biomass losses (Tongway et al., 2003; Çomaklı et al., 2012).

Both the quantity and quality of roughage obtained from pastures are critical factors for successful livestock operations (Heitschmidt et al., 1995). Consequently, sustainable pasture management necessitates practices aligned with sound ecological principles. Protecting existing pasture ecosystems and implementing effective rehabilitation strategies in degraded areas are of paramount importance. Achieving these goals requires a thorough assessment of current pasture conditions and the factors contributing to their decline. Effective rehabilitation strategies cannot be developed or implemented without a comprehensive understanding of the pasture vegetation. Therefore, prior to initiating any rehabilitation efforts, it is crucial to determine the botanical composition, yield, and quality characteristics of different pasture sections, especially those exhibiting variations in soil properties, topography, and plant cover. These data provide the foundation for implementing tailored rehabilitation practices (Çınar et al., 2014; Alay et al., 2016).

The nutritional value of feed derived from pastures and cultivated forage crops is directly linked to forage quality. A multitude of factors influence forage quality, including palatability, animal intake, digestibility, the presence of antinutritional compounds (such as toxins), chemical and morphological structure, and energy and protein content. Furthermore, environmental variables, such as climatic conditions (temperature and precipitation), seasonal variations, the relative proportions of grasses and legumes in the vegetation, altitude, and aspect, can significantly impact the quality of the resulting forage

(Kirilov, 2001; Kaya, 2008).

Several studies have investigated the factors influencing pasture yield and quality. Öner (2016) observed significantly higher dry matter yields (134.83 kg/da vs. 68.21 kg/da) and crude protein content (12.89% vs. 11.59%) in ungrazed areas compared to grazed areas within the Palandöken pastures of Erzurum, Türkiye, at an altitude of 2400 m. Conversely, ungrazed plots exhibited lower Neutral Detergent Fiber (NDF, 56.01-57.04%) and Acid Detergent Fiber (ADF, 36.53-39.90%) values. Slope also plays a crucial role, as demonstrated by Sürmen and Kara (2018) in Aydın province, Türkiye. Their analysis across five slopes (2%, 8%, 15%, 25%, and 30%) revealed dry matter yields ranging from 114.54 kg/da to 223.03 kg/da, with the 8% slope yielding the highest. The 8% slope also corresponded to the highest crude protein content (10.64%), while the 2% slope showed the highest Relative Feed Value (RFV, 101.35) and the lowest NDF content. Similarly, Severoğlu (2018) highlighted the negative correlation between slope and forage quality, reporting a dry matter yield of 56.43 kg/da, crude protein content of 8.14%, ADF content of 45.11%, and NDF content of 64.30%, with a botanical composition of 32.12% grasses, 25.28% legumes, and 42.60% other plant families.

This research investigates the livestock carrying capacity of Gito Plateau, located in the Çamlıhemşin district of Rize province within the Eastern Black Sea Region of Türkiye, through an examination of the nutritive value and mineral content of its plant species. Precise determination of plant composition and nutrient profiles is vital for the sustainable use of pasturelands and effective animal feeding. This study was conduct comprehensive nutrient and mineral analyses on plant samples, contributing valuable data to the development of effective pasture management practices for Gito Plateau.

2. Materials and Methods

2.1. Study Area

This study was conducted on Gito Plateau (Çamlıhemşin district, Rize province, Türkiye; 40° 54' 12'' N, 40° 54' 34'' E), a region known for its natural beauty in the Eastern Black Sea Region. Located approximately 2070 meters above sea level and 32 km from the district center, data were collected during 2023 and 2024. The study area's location and representative photographs are shown in figures 1 and 2, respectively. Gito Plateau is representative of the region's characteristic pasture ecosystems.

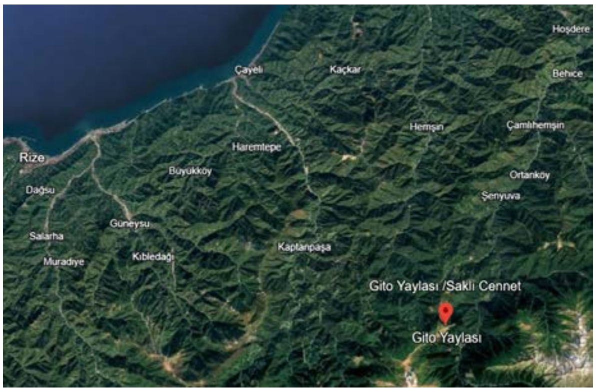

Figure 1. Location of the study area on the map (Google Earth).

Figure 2. Some photos taken from the study area (Date: July 22, 2023).

Soil samples collected from the study area underwent analysis to determine key physicochemical properties. The results revealed a clay-loam, texture with a saturation percentage of 74.8%, indicating a moderate water-holding capacity. The soil exhibited a strongly acidic reaction with a pH of 4.39. The total salt content was low (0.21%), categorized as slightly saline (low salinity), and the lime content was also low (0.11%), classified as slightly calcareous (low lime). The organic matter content was found to be moderate (2.01%). Available phosphorus (P_2O_5) and potassium (K_2O) levels were also moderate, measuring 5.29 kg/da and 38.16 kg/da, respectively. These findings suggest that the soil has a clay-loam texture, is strongly acidic, and has moderate levels of organic matter, phosphorus, and potassium, while salt and lime content are low. When the long-term meteorological data in Table 1 are analyzed, it is seen that Rize province has an average annual temperature of 14.5 °C and annual precipitation accumulation of 2301.2 mm (Anonymous, 2025).

Table 1. Long-term climate data of Rize province (Anonymous, 2025)

Rize (1928 – 2024)	Average Temperature (°C)	Average Highest Temperature (°C)	Average Lowest Temperature (°C)	Number of Rainy Days	Average Monthly Total Precipitation (mm)
January	6.9	10.7	3.9	14.69	231.9
February	6.8	10.8	3.7	14.25	185.2
Mart	8.1	12.0	4.9	15.80	161.3
April	11.7	15.5	8.4	14.48	95.2
May	16.0	19.4	12.7	14.31	96.6
June	20.4	23.6	16.8	14.13	134.1
July	22.9	26.0	19.7	13.68	151.0
August	23.3	26.6	20.1	14.18	195.3
September	20.3	24.1	17.0	14.64	257.5
October	16.4	20.5	13.1	14.85	296.3
November	12.3	16.5	9.1	13.57	255.3
December	8.9	12.9	5.8	14,11	241.5
Annual	14.5	18.2	11.3	172.7	2301.2

2.2. Methodology

Plant samples were collected from 12 distinct, different locations within the Gito Plateau study area during July of both 2023 and 2024. Vegetation was harvested at ground level using 50x50 cm quadrats (Türk and Özen, 2016). Fresh weights of the collected samples were measured *in situ* using a portable precision balance. Subsequently, samples were oven-dried at 70 °C for 48 hours to determine dry weights, which were then converted to yield per unit area (kg/da). The dried plant material was ground and homogenized using a mill equipped with a 1 mm sieve. The concentrations of crude protein (CP), acid detergent fiber (ADF), neutral detergent fiber (NDF), acid detergent protein (ADP), phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg) were determined using a Foss NIR Systems Model 6500 Win ISI II v1.5 NIRS instrument (Çaçan et al., 2014). Dry matter intake (DMI), digestible dry matter (DDM), relative feed value (RFV), digestible energy (DE), and metabolic energy (ME) were calculated from ADF and NDF values according to established equations from the literature: Digestible Dry Matter (DDM) = 88.9 - (0.779 x %ADF) (Oddy et al., 1983); Dry Matter Intake (DMI) = 120 / (%NDF) (Sheaffer et al., 1995); Relative Feed Value (RFV) = (DDM x DMI) / 1.29 (Sheaffer et al., 1995); Digestible Energy (DE) = 0.27 + 0.0428 x (%DDM) (Fonnesbeck et al., 1984); Metabolizable Energy (ME) = 0.821 x DE (Mcal/kg) (Khalil et al., 1986).

Finally, Ca/P and K/(Ca+Mg) ratios were calculated to assess the interrelationships among macro element concentrations.

2.3. Statistical Analysis

Descriptive statistics were employed to analyze the data collected for the parameters examined in this study. Data were processed using the JMP statistical software package to calculate descriptive measures. These measures included means, standard deviations, and ranges for each parameter.

3. Results

The nutrient composition of grass samples collected from Gito Plateau over a two-year period is summarized in Table 2. These data provide valuable insights into the overall nutritional quality of the pasture and potential variations in nutrient content between years.

Table 2 presents the yield and nutrient composition data obtained from the two-year analysis of grass samples collected from Gito Plateau. The average fresh yield (FY) was 480 kg/da, with values of 496±36.25 kg/da in the first year and 465±24.04 kg/da in the second year, demonstrating a slight inter-annual variation. Dry matter yield (DY) averaged 114 kg/da, with respective values of 120±7.34 kg/da and 108±7.05 kg/da for the first and second years. Crude protein (CP) content remained relatively consistent across both years, averaging 10.46%, with values of 10.48±1.83% and 10.43±1.44%.

Acid detergent fiber (ADF) content averaged 37.44%, with values of 37.60±4.02% and 37.28±2.86% for the first and second years, respectively. Neutral detergent fiber (NDF) averaged 69.10%, with values of 68.77±3.59% and 69.43±5.64% observed in the first and second years. Acid detergent protein (ADP) levels were very similar across both years, averaging 1.15%. Digestible dry matter (DDM) averaged 59.73%, with values of 59.61±2.23% and 59.86±3.13% for the two years. Dry matter intake (DMI) averaged 1.74%, showing minimal variation between years (1.74±0.15% and 1.73±0.09%). Relative feed value (RFV) averaged 80.42, with values of 80.63±11.53% and 80.20±9.38% for the first and second years. Digestible energy (DE) averaged 2.83 Mcal/kg, with values of 2.82±0.13 and 2.83±0.10 Mcal/kg. Metabolizable energy (ME) also showed little variation, averaging 2.32 Mcal/kg. Regarding mineral content, phosphorus (P) averaged 0.24%, potassium (K) averaged 1.53%, calcium (Ca) averaged 1.13%, and magnesium (Mg) averaged 0.30%. The Ca/P ratio averaged 4.81, with values of 4.96±1.74 and 4.67±1.71 for the two years. The K/(Ca+Mg) ratio averaged 1.07, with minimal variation between years (1.07±0.13 and 1.08±0.10). Overall, the nutrient composition of Gito Plateau pasture exhibited relatively small variations between the two years of the study, indicating a consistent nutritional profile.

Table 2. Yield and nutritional value of Gito Plateau pasture

Features Analyzed	1.Year	2.Year	Average
Fresh Yield (FY) (kg/da)	496±36.25	465±24.04	480
Dry Matter Yield (DY) (kg/da)	120±7.34	108±7.05	114
Crude Protein (CP) (%)	10.48±1.83	10.43±1.44	10.46
Acid Detergent Fiber (ADF) (%)	37.60±4.02	37.28±2.86	37.44
Neutral Detergent Fiber (NDF) (%)	68.77±3.59	69.43±5.64	69.10
Acid Detergent Protein (ADP) (%)	1.15±0.06	1.14±0.12	1.15
Digestible Dry Matter (DDM)	59.61±2.23	59.86±3.13	59.73
Dry Matter Intake (DMI)	1.74±0.15	1.73±0.09	1.74
Relative Feed Value (RFV)	80.63±11.53	80.20±9.38	80.42
Digestible Energy (DE) (Mcal/kg)	2.82±0.13	2.83±0.10	2.83
Metabolic Energy (ME) (Mcal/kg)	2.32±0.08	2.33±0.11	2.32
Phosphorus (P) (%)	0.23±0.08	0.24±0.09	0.24
Potassium (K) (%)	1.54±0.31	1.52±0.25	1.53
Calcium (Ca) (%)	1.14±0.09	1.12±0.09	1.13
Magnesium (Mg) (%)	0.30±0.05	0.29±0.05	0.30
Ca/P	4.96±1.74	4.67±1.71	4.81
K/(Ca+Mg)	1.07±0.13	1.08±0.10	1.07

4. Discussion

The nutritional composition of Gito Plateau pasture, as presented in Table 2, reveals valuable insights into its forage quality. The average dry matter yield (114.12 kg/da) observed in this study is notably lower than the maximum dry matter yield (827.3 kg/da) reported by Kılıç (2018) for Beypınarı pasture in Trabzon. This difference could be attributed to variations in environmental factors such as altitude, precipitation, soil type, and grazing management practices between the two locations. Furthermore, the fact that the pasture area under study was accessible to grazing also contributed to the low yield. This is because continuous and uncontrolled grazing can negatively impact the growth and development of plants, reducing their photosynthetic capacity and consequently leading to a decrease in biomass and overall productivity. The crude protein (CP) content of Gito Plateau pasture (10.46%) is also lower than the values reported by Kılıç (2018) (16.6%), Şahinoğlu (2010) (16.33-18.64%), Nadir (2010) (16.48-18.81%), and Aydın and Başbağ (2017) (19.19%) for different regions in Türkiye. This difference in CP content may reflect differences in plant species composition, soil fertility, and fertilization practices.

Regarding fiber content, the average ADF (37.44%) and NDF (69.10%) values for Gito Plateau are comparable to the ranges reported by Tutar and Kökten (2019) for Bingöl (ADF: 34.8-37.4%; NDF: 52.5-62.7%) but generally higher than those reported by Şahinoğlu (2010) (ADF: %29.82-31.99; NDF: %46.39-55.21), Nadir (2010) (ADF: %24.38-26.84; NDF: %34.59-36.32), and Parlak et al. (2015) (ADF: %29.40-31.73; NDF: %43.18-51.57). Higher fiber content can indicate lower digestibility and energy content. The digestible dry matter (DDM) of Gito Plateau pasture (59.73%) is lower than the value reported by Kılıç (2018) (61.0%) and Aydın and Başbağ (2017) (65.70%), which aligns with the observed differences in fiber content. The relative feed value (RFV) of Gito Plateau (80.42) is considerably lower than the values reported by Nadir (2010) (174.96-189.77) and Aydın and Başbağ (2017) (137.7), further supporting the lower overall forage quality compared to these studies.

The mineral content of Gito Plateau pasture also shows some variations compared to other studies. Phosphorus

(P) content (0.24%) is lower than the ranges reported by Şahinoğlu (2010) (0.40-0.43%) and Aydın and Başbağ (2017) (0.34%). Potassium (K) content (1.53%) is also lower than the values reported by Şahinoğlu (2010) (2.32-2.60%) and Aydın and Başbağ (2017) (2.42%). Calcium (Ca) content (1.13%) is within the range reported by Şahinoğlu (2010) (0.90-1.33%) and similar to Aydın and Başbağ (2017) (1.09%). Magnesium (Mg) content (0.30%) is also within the range reported by Şahinoğlu (2010) (0.26-0.36%) and similar to Aydın and Başbağ (2017) (0.31%). The K/(Ca+Mg) ratio (1.07) is lower than the range reported by Şahinoğlu (2010) (1.61-2.13). These differences in mineral content can be attributed to variations in soil mineral composition and plant species.

In conclusion, the nutritional quality of Gito Plateau pasture, while providing adequate forage, appears to be generally lower in terms of dry matter yield, crude protein, and relative feed value compared to other pastures studied in different regions of Türkiye. These differences highlight the importance of site-specific management strategies tailored to the unique characteristics of each pasture ecosystem.

5. Conclusion

This study investigated the nutritional value of Gito Plateau pasture in the Çamlıhemşin district of Rize province, Türkiye, during the summers of 2023 and 2024. Analysis of plant samples collected from 12 distinct locations revealed valuable insights into the forage quality of this important pasture ecosystem. The average dry matter yield was found to be 114.12 kg/da, with relatively consistent crude protein content averaging 10.46% across both years. Fiber content, as indicated by ADF (37.44%) and NDF (69.10%), suggests a moderate level of digestibility. Calculated feed quality parameters, including DDM (59.73%) and RFV (80.42), further characterized the nutritional value of the pasture. Mineral analysis revealed average concentrations of phosphorus (0.24%), potassium (1.53%), calcium (1.13%), and magnesium (0.30%), with calculated Ca/P and K/(Ca+Mg) ratios averaging 4.81 and 1.07, respectively.

The relatively consistent nutrient composition observed over the two-year study period suggests a stable forage resource. However, further research is needed to investigate the seasonal variations in nutrient content and the influence of grazing management practices on pasture quality. This study provides baseline data on the nutritional value of Gito Plateau pasture, which can be used to inform sustainable grazing management strategies and optimize livestock production in the region. These findings contribute to a better understanding of the pasture's potential to support livestock and highlight the importance of continued monitoring and management of this valuable natural resource in Türkiye's Eastern Black Sea Region.

Author Contributions

The percentages of the author contributions are presented below. All authors reviewed and approved the final version of the manuscript.

	M.İ.Ç.
C	100
D	100
S	100
DCP	100
DAI	100
L	100
W	100
CR	100
SR	100
PM	100
FA	100

C= concept, D= design, S= supervision, DCP= data collection and/or processing, DAI= data analysis and/or interpretation, L= literature search, W= writing, CR= critical review, SR= submission and revision, PM= project management, FA= funding acquisition.

Conflict of Interest

The author declared that there is no conflict of interest.

Ethical Consideration

Ethics committee approval was not required for this study because there was no study on animals or humans.

References

Alay F, İspirli K, Uzun F, Çınar S, Aydın İ, Çankaya N. 2016. Uzun süreli serbest otlatmanın doğal meralar üzerine etkileri. Gaziosmanpaşa Üniv Zir Fak Derg, 33 (1): 116 124.

Anonymous. 2025. T.C. Prime Ministry General Directorate of State Meteorological Affairs, Rize provincial directorate records. URL: https://www.mgm.gov.tr/veridegerlendirme/il-ve-ilceler-istatistik.aspx?k=undefined&m=RIZE (Accessed Date: March 2, 2025).

Aydın A, Başbağ M. 2017. Karacadağ'ın farklı yükseltilerindeki meraların durumu ve ot kalitesinin belirlenmesi. Anadolu Tar Bil Derg, 32(1): 74-84.

Beukes P C, Cowling RM. 2003. Non-selective grazing impacts on soil properties of the Nama Karoo. J Range Manag, 56: 547-552.

Çaçan E, Aydın A, Başbağ M. 2014. Korunan ve otlatılan iki farklı doğal alanın verim ve kalite açısından karşılaştırılması. TURKJANS, 1(Özel Sayı-1): 919-926.

Çınar S, Hatipoğlu R, Avcı M, İnal İ, Yücel C, Avağ A. 2014. Hatay ili Kırıkhan ilçesi taban meralarının vejetasyon yapısı üzerine bir araştırma. Gaziosmanpaşa Üniv Zir Fak Derg, 31(2): 52-60.

Çomaklı B, Fayetörbay D, Daşcı M. 2012. Changing of botanical composition and canopy coverage ratio in rangelands at different altitudes. Res J Agric Sci, 43(1): 17-21.

Fonnesbeck PV, Clark DH, Garret WN, Speth CF. 1984. Predicting energy utilization from alfalfa hay from the Western Region. Proc of Am Soci Anim Sci (Western Section), 35: 305-308.

Heitschmidt RK, Grings EE, Haferkamp MR, Karl MG. 1995. Herbage dynamics on two northern Great Plains range sites.

J Range Manag, 48: 211-217.

Holechek JL, Pieper RD, Herbel CH. 2011. Range management principles and practices. Sixth edition. Prentice Hall, Upper Saddle River, New Jersey, USA, pp: 444.

Kaya Ş. 2008. Kaba yemlerin değerlendirilmesinde göreceli yem değeri ve göreceli kaba yem kalite indeksi. Türk Bil Der Derg, 1(1): 59 64.

Khalil JK, Sawaya WN, Hyder SZ. 1986. Nutrient composition of Atriplex leaves grown in Saudi Arabia. J Range Manag, 39: 104-107.

Kılıç S. 2018. Trabzon ili Düzköy ilçesi Beypınarı merasında farklı gübre uygulamalarının meranın verim, kalite ve botanik kompozisyonuna etkileri üzerine bir araştırma. Yüksek Lisans Tezi, Tokat Gaziosmanpaşa Üniversitesi, Tokat, Türkiye, pp: 47.

Kirilov A. 2001. Lucerne quality and possibilities for its estimation, In : I. Delgado and J. Lloveras (Eds.), Quality in lucerne and medics for animal production. Zaragoza, CIHEAM, pp: 231-234, http://om.ciheam.org/om/pdf/a45/01600089.pdf (accessed date: October 23, 2016).

Lund HG. 2007. Accounting for the world's rangelands. Rangelands, 29(1): 3-10.

Nadir M. 2010. Tokat ili Yeşilyurt köyü doğal merasının botanik kompozisyon, kuru madde verimi ve kalitesinin belirlenmesi. Yüksek Lisans, Gaziosmanpaşa Üniversitesi, Tokat, Türkiye, pp: 72.

Oddy VH, Robards GE, Low SG. 1983. Prediction of in vivo dry matter digestibility from the fiber nitrogen content of a feed. In: Feed Information and Animal Production. (ed) Robards GE, Packham, RG. Common wealth Agricultural Bureau, Farnham Royal, UK, 395-398.

Öner T. 2016. Yüksek rakımlı korunan ve otlatılan mera kesimlerinde bazı bitki örtüsü ile toprak özellikleri arasındaki ilişkiler. Doktora Tezi, Atatürk Üniversitesi, Fen Bilimleri Enstitüsü, Tarla Bitkileri Anabilim Dalı, Erzurum, Türkiye, pp: 65.

Parlak AÖ, Parlak M, Gökkuş A, Demiray HC. 2015. Akdeniz (Çanakkale) meralarının ot verimi ve kalitesi ile botanik kompozisyonu ve bazı toprak özellikleri. COMU J Agri Fac, 3(1): 99-108.

Severoğlu S. 2018. Eğime bağlı olarak mera bitki örtüsünün değişimi. Yüksek Lisans Tezi, Atatürk Üniversitesi Fen Bilimleri Enstitüsü Tarla Bitkileri Anabilim Dalı, Erzurum, Türkiye, pp: 57.

Sheaffer CC, Peterson MA, Mccalin M, Volene JJ, Cherney JH, Johnson KD, Woodward WT, Viands DR. 1995. Acid detergent fiber, neutral detergent fiber concentration and relative feed value. In: North American Alfalfa Improvement Conference, Standard Tests to Characterize Alfalfa Cultivars, 2-7 March, Minnesota, USA, URL: https://www.naaic.org/resource/stdtests.php (Accessed Date: March 2, 2025).

Snyman HA. 2005. Rangeland degradation in a semi-arid South Africa. I: influence on seasonal root distribution, root/shoot ratios, and water-use efficiency. J Arid Environ, 60: 457-481. https://doi.org/10.1016/j.jaridenv.2004.06.006

Sürmen M, Kara E, 2018. Aydın ili ekolojik koşullarında farklı eğimlerdeki mera vejetasyonlarının verim ve kalite özellikleri. Derim Derg, 35(1): 67-72.

Şahinoğlu O. 2010. Bafra ilçesi Koşu köyü merasında uygulanan farklı ıslah yöntemlerinin meranın ot verimi, yem kalitesi ve botanik kompozisyonu üzerine etkileri. Doktora Tezi, Ondokuz Mayıs Üniversitesi, Samsun, Türkiye, pp: 57.

Tongway DJ, Sparrow AD. Friedel MH. 2003. Degradation and recovery processes in arid grazing lands of central Australia. Part I: Soil and Land Resources. J Arid Environ, 55: 302-326.

Tutar H, Kökten K, 2019. Mera vejetasyon özelliklerinin farklı yöneylere göre değişimi. Türk Tar Araş Derg, 6(3): 312-318.

Türk M, Özen F. 2016. ağlasun orman içi meralarının verim ve kalitesinin belirlenmesi. Ziraat Fak Derg, 11(1): 82-88.

Black Sea Journal of Agriculture

doi: 10.47115/bsagriculture.1634045

Open Access Journal
e-ISSN: 2618 – 6578

Research Article
Volume 8 - Issue 2 : 240-250 / March 2025

DOES ORGANIC PRODUCTION AND MARKETING TRAINING IMPROVE THE AGRICULTURAL BUSINESS SKILLS OF RURAL WOMEN FARMERS? A CASE STUDY FROM TÜRKİYE

Esin HAZNECİ[1]*, Kerem HAZNECİ[1], Cevahir KAYNAKÇI BAYDAR[2], İsmet BOZ[3]

[1]Ondokuz Mayıs University, Faculty of Agriculture, Department of Agricultural Economics, 55139, Samsun, Türkiye
[2]Kahramanmaraş Sütçü İmam University, Faculty of Agriculture, Department of Agricultural Economics, 46100, Kahramanmaraş, Türkiye
[3]United Arab Emirates University, Faculty of Agriculture and Veterinary Medicine, Department of Integrative Agriculture, 15551, Al Ain, United Arab Emirates

Abstract: The primary objective of this study is to evaluate the training activities provided to the female farmers supplying products to the organic product market in Sürmeli village, Bafra District, Samsun, Türkiye. A survey was used to collect data from female farmers who sell their products in the organic market and other farmers who do not sell their products in the organic market. The full-counting method was used to obtain the data. Within the scope of the research, a survey was administered to all participant farmers twice - before and after the training. The training was provided only to the female farmers producing organic products. When analysing the enterprises, the Kirkpatrick Program Evaluation Model, one-way analysis of variance, and covariance analysis were performed to determine the effectiveness of the training on organic agricultural production and marketing. Comparisons of the scores that measure the total knowledge levels of both production and marketing of organic production revealed that the score in the experimental group was statistically higher than that in the control group, and this difference was due to the training provided to the experimental group (R Squared = 0.633, 0.866). It can be said that among the participant farmers, those having a higher level of knowledge of organic production and marketing issues will carry out agriculture activities more successfully.

Keywords: Kirkpatrick program evaluation model, Marketing, Organic production, Women's organization, Türkiye

***Corresponding author:** Ondokuz Mayıs University, Faculty of Agriculture, Department of Agricultural Economics, 55139, Samsun, Türkiye.
E mail: esin.hazneci@omu.edu.tr (E. HAZNECİ)
Esin HAZNECİ https://orcid.org/0000-0002-8695-028X
Kerem HAZNECİ https://orcid.org/0000-0002-2567-1260
Cevahir KAYNAKÇI BAYDAR https://orcid.org/0000-0003-3785-528
İsmet BOZ https://orcid.org/0000-0001-7316-9323

Received: February 05, 2025
Accepted: March 03, 2025
Published: March 15, 2025

Cite as: Hazneci E. Hazneci K. Baydar Kaynakçı C. Boz İ. 2025. Does organic production and marketing training improve the agricultural business skills of rural women farmers? A case study from Türkiye. BSJ Agri, 8(2): 240-250.

1. Introduction

The development of local organic markets is one of the most critical elements in the development of organic farming. To ensure sustainable agricultural production and sufficient income for farmers in a region, it is necessary to have enough customers willing to buy these products. Generally, consumers with higher incomes and education levels can be expected to be ready to pay higher prices for organic products (Grimm et al., 2023). Consumers generally make this decision because they believe organic products provide additional benefits compared to conventionally produced foodstuffs, and more health conscious consumers also look for safer ways to buy food in every country. Local organic markets, where producers and consumers communicate face-to-face, are one way to offer organic products to customers. In local organic markets, which is an example of direct marketing, products are delivered directly to the consumer without intermediaries, brokers, or wholesalers (Kaya, 2009). It has been determined that organic markets are concentrated in metropolitan cities where education and income levels are high in Türkiye (Eti, 2014). However, increasing the number of organic markets is an important factor in facilitating consumers' access to organic agriculture and food products (Eryılmaz et al., 2015). Local organic markets make significant contributions to the development of a sustainable organic production value chain by increasing product diversity and ensuring continuity in the consumption of organic products (Ayan et al., 2017). In addition, organic markets pave the way for fair trade, provide opportunities for small producers who cannot meet the demand to enter the market (Qiao et al., 2016), enable production in line with consumer demand, protect biodiversity. Organic and fair trade production is also seen as important in facilitating the organization of farmers and the democratic management of farmer cooperatives (Chen and Scott, 2014).

In the literature review conducted within the scope of the research, a large number of studies, especially among international literature, were found regarding the

Kirkpatrick Model, which constitutes the method of the research (McLean and Moss, 2003; Kaya et al., 2015; Jaafar et al., 2022; Gifford et al., 2023; Mignouna et al., 2023; Stefan et al., 2023). There are also studies on organic production, organic markets, and organic marketing (Aertsens and Koen, 2009; Arslantürk and Aysen, 2015; Ağızan and Bayramoğlu, 2023). In addition, there are also studies on the factors affecting the consumption of organic products in Türkiye and the attitudes of consumers towards organic products (Eti, 2014; Arslan, 2016). In Türkiye, studies have been conducted on women's markets created by organic producers (Koday and Çelikoğlu, 2011; Şahan et al., 2014) and the adoption of organic agriculture by women in rural areas (Erem and Atsan, 2013). The literature review revealed that no study has been conducted that evaluated a planned and systematic training study for producers supplying products to organic markets in Türkiye using scientific methods. In the preliminary study conducted in Sürmeli village, it was determined that the education level of women and their participation in family decisions were low. The Sürmeli Village Organic Market, which has recently turned into a women's organization, has provided women in the village with the opportunity to develop themselves through vocational training and entrepreneurship. However, benefiting from this opportunity will undoubtedly be possible by conducting training activities for women and evaluating these activities impartially. The inadequacy of such evaluation studies to date makes it difficult to develop concrete proposals on the training plans and contents to be made on the subject. The subject of the study is important both in terms of evaluating a training activity on increasing the professional capacity of women entrepreneurs in the region and in terms of the sustainability of organic production. This study is considered important in terms of facilitating the spread of women's organic organizations. It is thought that the Sürmeli village organic market is the first such market established at the village level in Türkiye and that every practice and strategy that leads to success in this market will guide other villages and local markets. Finally, marketing is undoubtedly a factor that directly affects the profitability of businesses. In order for agricultural enterprises to continue their commercial activities through earning higher profits, it is deemed necessary for producers who lack sufficient knowledge about production and marketing to receive training on the subject. For this reason, the study aimed to evaluate the training activities to be given to female farmers who supply products to the organic product market operating in Sürmeli village in the Bafra District, Samsun.

2. Materials and Methods

2.1. Determining the Farmers to be Surveyed, Monitoring the Training, and Applying the Surveys

Samsun Province, located in the Black Sea region of Türkiye, has among 82 provinces become Türkiye's highest vegetable producing region with 878167 tons of vegetable production. Approximately 76% of the total vegetable production of Samsun is produced in Bafra District (680842 tons) (TUIK, 2022) (Figure 1).

Figure 1. A survey of the research areas in Türkiye, Samsun Province, Bafra District (ZEEMAPS, 2024).

On the Bafra Plain, which is one of the most fertile plains in Türkiye and gives its name to the district, intensive vegetable cultivation is carried out, and the plain also enables the cultivation of organic products to be widespread. For this reason, the organic market in Sürmeli village in the Bafra District and the work carried out here are considered important. In line with the general purpose of the research, first of all, female farmers who supply products to the organic market of Sürmeli village were determined, and pre-training questionnaires prepared for these farmers were applied. These farmers formed the experimental group of the research. At the same time, a control group of the same number of female farmers in Sürmeli village who do not supply products to the organic market was randomly selected, and pre-training questionnaires were applied to this group as well. Then, the trainings given to women producers engaged in organic production for 1 day a week for 4 hours for 3 months in March-April-May 2019 were monitored. The trainings were given by the faculty members of Ondokuz Mayıs University, Faculty of Agriculture, Department of Agricultural Economics. The content of the training given to the women included organic products, organic production and its principles, production planning, marketing of organic products and agricultural marketing, customer relations, production and marketing ethics, packaging in the organic market, hygiene rules, and bench layout. The training programme continued for three months. To evaluate the training given to the female farmers supplying products to the Sürmeli village organic market and to determine whether the training was successful, second questionnaires were prepared to include the training topics. These questionnaires were applied to the female farmers engaged in organic production (experimental group) and to the control group that undertook conventional production, which was determined in the first stage. During this period, no training was given to the control group, and the training was only applied to the experimental group. Questionnaire forms were filled out face-to-face with the female farmers.

Although it was stated in the first meeting held in the village while the project was being prepared that there was a total of 24 organic producers producing organic vegetables and fruits, it was noted that the number of producers regularly supplying products to the market was 20 when the survey phase was started. It has been determined that three of the 24 producers produce only enough for themselves and do not come to the market, and one of them does not bring their products to the market but sells from home to her close circle and to those who come to her directly. For this reason, the study was carried out with 20 female farmers who supply products to the market. This is a women's organization, and all of its members are women, however, since one of the women passed away, her husband has continued to produce and open stalls at the market. Therefore, only one member was male. All of the members actively participated in the training. Producers forming the control group in the research region were randomly selected from among the producers undertaking conventional production in the area, and 24 producers were interviewed - the same number as the experimental group size determined at the beginning. In order to obtain the research data, a total of 88 questionnaires, 44 before and 44 after the training, were applied and pre-test post-test result tables were created accordingly.

2.2. Statistical Analysis

The research data were obtained in the 2019-2020 production period. The Fisher’s exact test and independent-sample t-tests were applied to determine whether there was a difference between the experimental group and the control group regarding the findings obtained as a result of the research. In addition, covariance analysis was conducted to determine whether the training on organic agricultural production and marketing was effective in the research. Percentage and frequency values, mean and standard deviations were used in the analysis of the data. The Kirkpatrick Program Evaluation Model was used to evaluate training activities for the farmers. This model is a four-stage model developed by Kirkpatrick that aims to rationally evaluate each stage from the beginning of the programme to its conclusion. It can be used to evaluate training programmes for human resources (McLean and Moss, 2003; Kaya et al., 2015; Jaafar et al., 2022; Gifford et al., 2023; Mignouna et al., 2023; Stefan et al., 2023) and can be an effective tool. The Kirkpatrick Program Evaluation Model consists of four-level measurements applied at different periods of the developed programme. These are: 1) reaction; 2) learning situation; 3) behaviour change; and 4) results. At each of these four stages, the right assessment design, data collection, and analysis of the data are very important (Kirkpatrick, 1995; Kirkpatrick and Kirkpatrick, 2007). The training is hypothesized to enable farmers to enhance their skills and knowledge in organic production and marketing (OPM), with a guarantee of making them more efficient and productive. The author developed a framework drawing based on the literature to measure the impact of the OPM training (Figure 2).

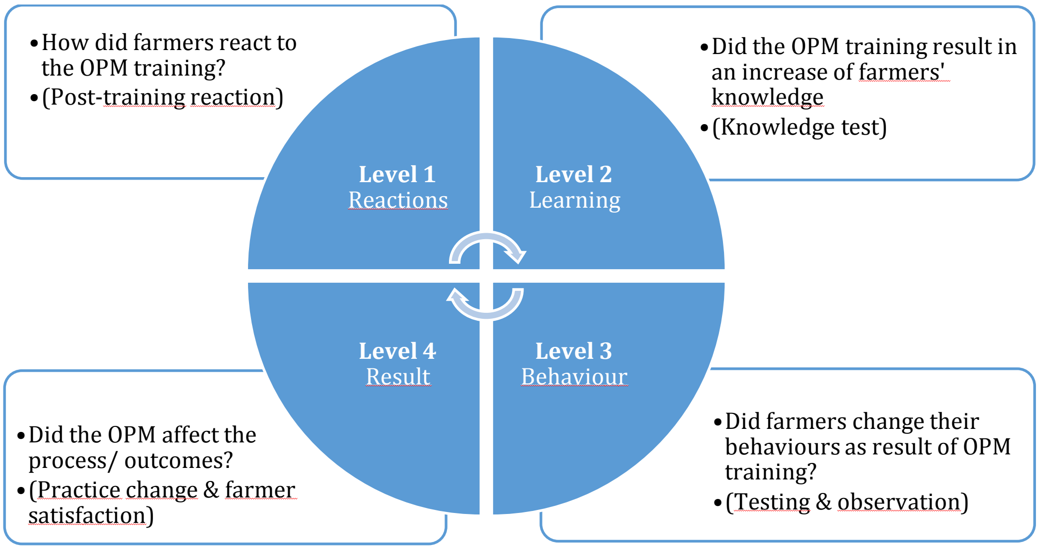

Figure 2. Hierarchical Kirkpatrick Model for organic production and marketing (OPM) training (Author' composition)

Level 1. Reaction: The purpose of the reaction stage is to measure the reaction of the target audience, who have been trained within the scope of the programme. Data collection related to this stage can be done at the time of the training activities, right after their completion, or during the periods when the participants put the gains from the programme into practice. The target audience of agricultural extension and rural education programmes can generally be either a farmer group, village women in a certain region, or young people living in rural areas (Kirkpatrick, 1995; Sahni, 2020; Mignouna et al., 2023). Questionnaires used in the data collection process in reaction measurements are preferred because they give more concrete information and can be evaluated easily.

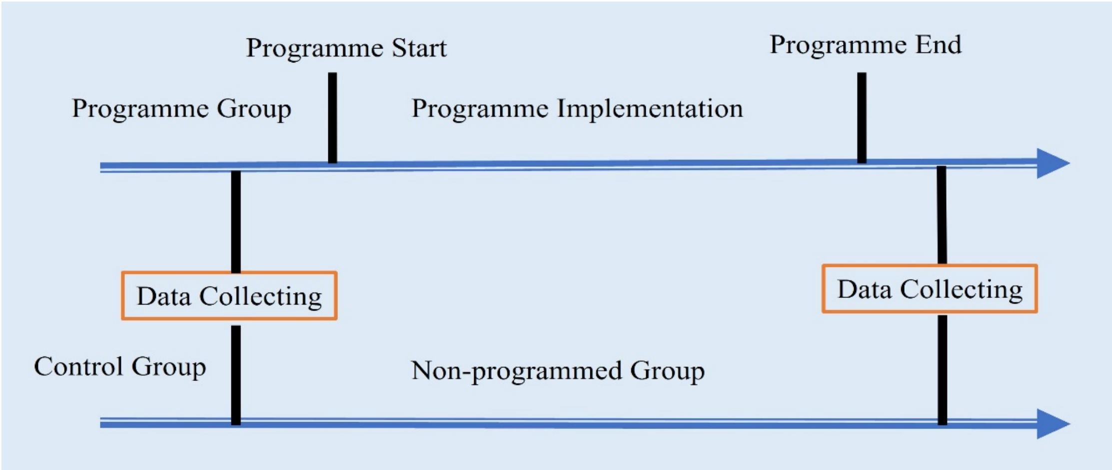

Figure 3. Pre-test-post-test the experiment and control group design for OPM (Author' composition)

Level 2. Learning Situation: This stage of the programme evaluation model aims to critically assess the information obtained by the participants from the programme. From literature, the author developed the design used in information measurement is shown in figure 3. The first line of the design shows the evaluation process applied to the experimental (programme) group, that is, the audience subjected to the training programme, and the second line shows the evaluation process applied to the control group. The control group is selected from people who did not participate in the training programmes. Surveys containing the same questions were administered to both groups before and after the training. The results were compared.

Level 3. Behaviour Change: This stage of the programme evaluation model aims to measure the extent to which the knowledge, attitudes, and behaviours obtained by the participants from the programme are applied in their business and professional lives.

Level 4. Results: The final stage of the model is the analysis of the programme results. Since the present study was aimed at comparing the learning outcomes of a training programme prepared for female farmers engaged in organic agriculture, the Kirkpatrick Program Evaluation Model's design was used, applying a two-group pre-test and post-test design.

3. Results and Discussion

The organic movement in the village started eight years ago. At the beginning, it was observed that none of the producers in the village had any knowledge about organic production. For this reason, it was determined that the women producers needed to receive training to obtain knowledge about organic production and marketing. Organic winter vegetables, organic summer vegetables, and fruits were observed in the village during the research, including leeks, broccoli, carrots, beets, radishes, spinach, cabbage, lettuce, arugula, cress, parsley, dill, cauliflower, artichokes, peas, beans, eggplant, cucumbers, tomatoes, peppers, broad beans, okra, potatoes, garlic, onions, Jerusalem artichoke, strawberries, and persimmon. These products are sold every Sunday between 8:00 and 18:30 in the organic marketplace in Sürmeli village, built by Samsun Metropolitan Municipality. The average age of the organic producers in the experimental group is 47.70 years, and more than half (55%) of the producers participating in the survey are under the age of 50. Female participants constituted 95% of the organic producers while 80% were married. The general profile of organic producers in the village is a middle-aged married woman (Table 1). It is noteworthy that the majority of the producers (80% in the experimental group and 70.8% in the control group) are primary school graduates, and their education levels are low. On keeping farm records, 35% of the organic producers in the experimental group and approximately 21% of the producers in the control group stated that they undertook this activity. While 15% of the producers in the experimental group use credit for inputs, approximately 38% of the producers in the control group use credit for inputs. It was ascertained that 85% of the producers in the experimental group and 95.8% of the members of the control group have social security (SSK, BAĞKUR, Retirement Fund, Green Card). It was determined that 15% of the organic producers in the experimental group do not have any social security (Table 1). Abacı and Demiryürek (2019), in their study with vegetable producers in Bafra, the same region as the research, determined that the farmers were 46 years old on average and mostly primary school graduates.

Table 1. Socio-economic characteristics (categorical variables)

Socio-economic characteristics	The experimental group Frequency (%)	Control group Frequency (%)	Fisher p
Age			
50 and younger	11 (55.0)	1 (4.2)	0.01**
Over 50	9 (45.0)	23 (95.8)	
Education level			
Primary school graduate	16 (80.0)	17 (70.8)	0.728
Above primary school	4 (20.0)	7 (29.2)	
Marital status			
The married	18 (90.0)	22 (91.7)	0.624
Single	2 (10.0)	2 (8.3)	
Gender			
Female	19 (95.0)	0 (0.0)	0.001**
Male	1 (5.0)	24 (100.0)	
Off-farm occupation			
Yes	4 (20.0)	6 (25.0)	0.489
No	16 (80.0)	18 (75.0)	
Social security status			
There is	17 (85.0)	23 (95.8)	0.237
No	3 (15.0)	1 (4.2)	
Business record keeping			
Yes	7 (35.0)	5 (20.8)	0.238
No	13 (65.0)	19 (79.2)	
Tractor asset			
Yes	14 (70.0)	21 (87.5)	0.145
No	6 (30.0)	3 (2.5)	
Credit usage for inputs			
Yes	3 (15.0)	9 (37.5)	0.77
No	17 (85.0)	15 (62.5)	

** Significant at 0.01 (Author' own calculation)

As a result of the research, it was found that the average age of the producers in the control group was higher than the experimental group, and there was a statistically significant difference in age between the experimental group and the control group ($p<0.01$) (Table 1 and 2). Although it was aimed to meet with the female farmers who did not supply the same amount to the organic market as the experimental group at the beginning of the research, as a result of the examinations, it was revealed that women did not participate in the production activities in the region and that most men continued their production activities. Therefore, a statistically significant difference was found between the two groups in terms of gender ($p<0.01$) (Table 1). Of the total organic producers, 75% have a non-farm income. They grow organic plants on an average of 1.49 hectare of land. They earn approximately 257 $ per month, and their families consist of an average of 3.70 people (Table 2). At first glance, it might seem that the income from organic farming and marketing isn't very high. But because this money comes from women's businesses, it can be said that it will help families have a long-term source of income. The mean age of the producers in the control group was determined as 59.06. The average size of producer families is 2.55 people. The reason why the family size of these producers was lower than the experimental group is that the children of the families had left the village. The producers in the experimental group, on the other hand, live with their children since they are primarily middle-aged married people. Therefore, there was a statistically significant difference in terms of the number of households ($p<0.01$) (Table 1 and Table 2)

Table 2. Socio-economic characteristics (continuous variables)

Socio-economic characteristics	The experimental group Mean (SD)	Control group Mean (SD)	t	P
Age (years)	47.60 (12.78)	59.06 (9.96)	-3.60	0.001**
Monthly income ($)	257 (741)	237.6 (2714)	0.170	0.876
Own land assets (hectare)	1.49 (1.39)	1.85 (1.09)	-0.973	0.336
Number of households (person)	3.70 (1.78)	2.56 (1.29)	2.24	0.031*

* Significant at 0.05, ** Significant at 0.01 (Author' own calculation)

It has been found that most of the people in the control group are engaged in cattle farming. For this reason, the average land size of 1.85 hectare calculated for these producers is relatively small. However, more often the farmers are trying to continue production by using the rental method. More than half of them (55%) use rental land, and the average annual rental land size is 4.5 hectare (Table 2). The property itself is relatively smaller. These producers do a lot of work with livestock, and they only grow a small number of plants as a plant production activity. They mostly grow wheat, followed by barley, silage corn, and vetch. In the first surveys that were done with the control group, it was found that most farmers had heard of organic farming, but did not know what it meant, even though they lived in the same village. Farmers in the experimental group and control group took a pre-test before they learned about organic farming and marketing (Table 3 and 4). The average values of the experimental group were found to be higher than the average values of the control group in terms of the variables examined. However, there was no significant difference between the two groups except for the fourth topic regarding organic production ($p>0.05$) (Table 3).

Table 3. Comparison of the knowledge levels of the experimental and control groups on organic production (pre-test)

	Issues related to organic production	The experimental group Mean (SD)	Control group Mean (SD)	t	P
1	Knowing the difference between organic and conventional production	0.75 (0.44)	0.67 (0.48)	0.557	0.083
2	Knowing the basics of organic production	0.60 (0.50)	0.50 (0.51)	0.925	0.230
3	Proper use of organic and green fertilizers	0.55 (0.51)	0.42 (0.50)	0.869	0.390
4	Ability to properly manage alternation	0.55 (0.52)	0.25 (0.44)	2.089	0.043*
5	Applying soil conservation measures	0.50 (0.51)	0.29 (0.46)	1.410	0.208
6	Able to apply methods to increase plant resistance	0.15 (0.36)	0.04 (0.20)	1.238	0.223
	Total knowledge level on organic production issues	3.10 (2.07)	2.12 (1.48)	1.810	0.073

* Significant at 0.05 (Author' own calculation)

According to the pre-test results, there was a significant difference between the experimental group and the control group in terms of understanding and sustaining customer satisfaction ($p<0.05$). However, there was no difference in terms of general knowledge levels and total score regarding marketing ($p>0.05$) (Table 4). Arslantürk and Aysen (2015) interviewed seven organic market tradesmen (producers/sellers) selling in the only organic market of Ankara, the capital of Türkiye. Like the research area in the present study, this organic market was also a small market. It was concluded that the sellers of organic products conduct this business primarily to serve people's desire to live more healthily, and then to make a profit.

Table 4. Comparison of the knowledge levels of the experimental and control groups on the marketing of organic products (pre-test)

	Issues related to the marketing of organic products	The experimental group Mean (SD)	Control group Mean (SD)	t	P
1	Knowing the importance of customer relations in the marketing of organic products	0.50 (0.51)	0.71 (0.46)	-1.41	0.165
2	Knowing how to behave to make the customer permanent	0.70 (0.47)	0.63 (0.49)	0.512	0.641
3	Understanding the difference between product sales and product marketing in customer relations and not only focusing on sales	0.20 (0.41)	0.25 (0.44)	-0.386	0.702
4	Understand and maintain customer satisfaction in relations with customers	0.80 (0.41)	0.50 (0.50)	2.117	0.040*
5	Providing sufficient information about the content of the product	0.70 (0.47)	0.63 (0.49)	0.512	0.611
6	Convincingly explaining the difference of the product sold from other products	0.60 (0.53)	0.46 (0.51)	0.925	0.360
7	Relationships with customers are not limited to sales; they also include personal issues and focus on sincerity	0.55 (0.51)	0.33 (0.48)	1.44	0.156
	The total score on issues related to the marketing of organic products	4.05 (0.99)	3.50 (1.38)	1.48	0.145

* Significant at 0.05 (Author' own calculation)

It is noteworthy that, in terms of the variables examined as a result of the training given on organic production, the averages of the experimental group are generally higher than the averages of the control group. However, there was no statistically significant difference in the first six criteria ($p>0.01$). When the total scores measuring the total knowledge level of the producers on organic production issues were compared, it was determined that the score of the experimental group was statistically higher than the control group, and this difference was due to the education given ($p<0.01$) (Table 5). The knowledge levels of producers on marketing organic products were compared.

Table 5. Comparison of the knowledge levels of the experimental and control groups on organic production (post-test)

	Issues related to organic production	The experimental group Mean (SD)	Control group Mean (SD)	t	P
1	Knowing the difference between organic and conventional production	0.80 (0.41)	0.62 (0.49)	1.261	0.214
2	Knowing the basics of organic production	0.81 (0.41)	0.54 (0.51)	1.827	0.075
3	Proper use of organic and green fertilizers	0.65 (0.49)	0.67 (0.48)	-0.113	0.910
4	Ability to properly manage alternation	0.70 (0.47)	0.46 (0.51)	1.623	0.112
5	Applying soil conservation measures	0.60 (0.50)	0.42 (0.50)	1.203	0.236
6	Able to apply methods to increase plant resistance	0.50 (0.51)	0.42 (0.50)	0.542	0.591
	Total knowledge level on organic production issues	4.2 (1.43)	1.61 (1.44)	5.89	0.001**

** Significant at 0.01 (Author' own calculation)

Table 6. Comparison of the knowledge levels of the experimental and control groups on the marketing of organic products (post-test)

	Issues related to the marketing of organic products	The experimental group Mean (SD)	Control group Mean (SD)	t	P
1	Knowing the importance of customer relations in the marketing of organic products	0.95 (0.22)	0.71 (0.46)	2.13	0.039*
2	Knowing how to behave to make the customer permanent	0.65 (0.49)	0.71 (0.48)	0.779	0.441
3	Understanding the difference between product sales and product marketing in customer relations and not focusing only on sales	0.45 (0.51)	0.33 (0.48)	0.779	0.440
4	Able to comprehend and maintain customer satisfaction in relations with customers	0.75 (0.44)	0.29 (0.46)	3.32	0.002**
5	Providing sufficient information about the content of the product	0.55 (0.50)	0.50 (0.51)	0.323	0.748
6	Convincingly explaining the difference of the product sold from other products	0.60 (0.50)	0.46 (0.51)	0.925	0.360
7	Relationships with customers are not limited to sales; they also include personal issues and focus on sincerity	0.60 (0.50)	0.42 (0.50)	1.203	0.236
	The total score on issues related to the marketing of organic products	4.55 (1.32)	3.42 (1.77)	3.013	0.004**

* Significant at 0.05, ** Significant at 0.01 (Author' own calculation)

A statistically significant difference was found between the experimental group and the control group in terms of knowing the importance of customer relations in marketing organic products ($p<0.005$) (Table 6). The mean score of the experimental group (0.95) was higher than the mean score of the control group (0.71). Similarly, a statistically significant difference was observed in terms of comprehending and sustaining customer satisfaction, and the average score of the experimental group (0.75) was considerably higher than the score of the control group (0.29) ($p<0.01$). As a result, when all the criteria were evaluated together, and the total score was compared on the issues related to the marketing of organic products, it was determined that the total score of the experimental group was statistically higher than the control group ($p<0.01$), and all these differences were caused by the training given to organic producers (Table 6).

In the research, covariance analysis was carried out to determine whether the training on organic agricultural production and marketing was effective (Table 7 and Table 8). Since organic farming activities in the village were started as a women's entrepreneurship and women's movement, the experimental group was chosen for this purpose.

Table 7. Covariance analysis results on production-related subjects (dependent variable, post-test scores)

	Type III sum of squares	Degrees of freedom	Mean squares	F	P
Validated model	103.967a	3	34.656	22.995	0.000
Constant term	40.094	1	40.094	26.604	0.000
Group	28.682	1	28.682	19.031	0.000
Pre-test	26.767	1	26.767	17.761	0.000
Group *pre-test	2.362	1	2.362	1.567	0.218
Error	60.283	40	1.507		
Total	497.000	44			
Verified Total	164.250	43			

R Squared = 0.633 (Adjusted R Squared = 0.605) (Author' own calculation)

What is important here is that they had not received any training in organic agricultural production and marketing before this programme, and therefore the knowledge levels of both groups before the training were determined to be close to each other. To carry out the analysis of covariance, the collected data were first checked for compliance with the assumptions. In this context, necessary statistical controls were made in terms of normality, linearity, homogeneous distribution of variances, and homogeneous distribution of the regression curve. The total value of the answers given in the pre-test and post-test to the six training topics covered in agricultural production is in table 7 and 8, the total values of the answers given in the seven questions on agricultural marketing are shown. The pre-test results significantly differed from the post-test scores after the training on organic production and marketing (Table 7 and 8). However, the effect of the groups' pre-test interaction on the post-test was statistically insignificant. While the pre-test results did not show any statistical difference between the groups, the post-test results did. This shows that the training given to the experimental group was effective and achieved its purpose.

Table 8. Results of covariance analysis on marketing-related subjects (dependent variable, post-test scores)

	Type III sum of squares	Degrees of freedom	Mean squares	F	P
Validated model	48.884a	3	16.295	86.351	0.000
Constant term	11.437	1	11.437	60.607	0.000
Group	3.765	1	3.765	19.953	0.000
Pre-test	2.922	1	2.922	15.484	0.000
Group *pre-test	0.689	1	0.689	3.653	0.063
Error	7.548	40	0.189		
Total	801.000	44			
Verified Total	56.432	43			

R Squared = 0.866 (Adjusted R Squared = 0.856) (Author' own calculation)

Education was held for 150 farming women from five villages of Karnataka's Dharwad Taluk District in India on the concepts of organic farming and the use of farm and animal waste. The findings showed that women's knowledge before the intervention was low, and the training provided was effective in educating women about organic agriculture (Nagnur et al., 2012). Chernbumroong et al. (2022) applied the Kirkpatrick Model to evaluate the effectiveness of training to improve the knowledge and performance of eight local Thai farmers. The overall result showed that the participants responded positively to the training. Another study on the learning success of farmers during the transition to market-oriented organic agriculture in rural Uganda also yielded positive results after training (Hauser et al., 2010).

The effects of the training given to the farmers on organic production and marketing are seen more concretely in table 9 and 10. In production subjects, the average of the experimental group was estimated as 3.971 out of six, which is the total score, while this score remained at 1.732 in the control group. The mean difference between the two groups was 2.239, which was statistically significant (Table 9).

In agricultural marketing subjects, the average of the experimental group was 5.175 out of seven, which is the total score, while the average of the control group was 3.269. The mean difference between the two groups was 1.906, which was statistically significant (Table 10).

Table 9. Estimates of production and paired comparison (dependent variable, production post-test)

Group	Mean	SE	Mean difference	SE	P_b
Experimental group	3.971a	0.282	2.239*	0.389	0.000
Control group	1.732a	0.257	-2.239*	0.389	0.000

The covariances in the model were calculated according to the pre-test = 2.5682 value. Bonferroni method was used for comparison (Author' own calculation)

Table 10. Estimates and paired comparison on marketing (dependent variable, marketing post-test)

Group	Mean	SE	Mean difference	SE	P_b
Experimental group	5.175a	0.099	1.906*	0.134	0.000
Control group	3.269a	0.089	-1.906*	0.134	0.000

Covariances in the model pre-test = 3.0909 calculated according to its value. Bonferroni method was used for comparison (Author' own calculation)

4. Conclusion

Organic products are extremely beneficial to consumers and contribute to people living more healthily, thereby reducing the need for medical services. Additionally, while providing organic producers with the opportunity to practice conscious agriculture, it contributes both to assisting them to obtain a more sustainable income and leading them to live in better harmony with natural resources and the environment in rural areas. Therefore, the benefits of encouraging organic production and consumption for all segments of society cannot be denied.

The research findings showed that the experimental group that was trained was more knowledgeable in both production and marketing than the control group that did not receive training. As a result, the training provided was effective on organic producers. It can be said that farmers who have a higher level of knowledge of organic production and marketing will carry out agribusiness activities more successfully. Therefore, new farmers who want to join organic production and marketing farmers must be trained. For farmers who currently produce organically, they should ensure that they receive training on new products, production methods and marketing at regular intervals.

The development of organic agriculture in the region will contribute not only to the farmers living here, but also to the country's economy. However, this will only be possible by selecting determined producers and raising awareness among them through various training and extension activities. Conscious producers and sellers will be able to create continuous marketing potential for their products. In addition to all these, the market needs to be developed to ensure the sustainability of organic production in the village. For farmers to meet consumer demands and increase their income levels, they must first increase their product range and then enlarge their land holdings by either renting or purchasing. Only when these conditions are met will the market and economy remain viable. The main limitation of this study was that the Sürmeli case, the only organic women's organization in the region, was in a small area. Therefore, future studies should be expanded with data from a larger number of farms producing organic products in larger areas.

Author Contributions

The percentages of the authors' contributions are presented below. All authors reviewed and approved the final version of the manuscript.

	E.H.	K.H.	C.K.B	İ.B.
C				
D	50			50
S				
DCP	50	25	25	
DAI	30	10	10	50
L	30	20	30	20
W	40	10	10	40
CR	50			50
SR				
PM				
FA				

C= concept, D= design, S= supervision, DCP= data collection and/or processing, DAI= data analysis and/or interpretation, L= literature search, W= writing, CR= critical review, SR= submission and revision, PM= project management, FA= funding acquisition.

Conflict of Interest

The authors declared that there is no conflict of interest.

Ethical Consideration

Ethical approval was obtained for this study from the Ondokuz Mayıs University Social and Human Sciences Ethics Committee (approval date: March 13, 2018, protocol code: 2018 / 72-108).

Acknowledgments

This study is based on data derived from the project numbered PYO.ZRT.1901.18.009, supported by the Ondokuz Mayıs University. I would like to express my sincere gratitude to Ondokuz Mayıs University for their generous funding and support, which enabled this research.

References

Abacı Nİ, Demiryürek K. 2019. Factors affecting farmers' decision making on product pattern: A case of vegetable producers in Bafra district of Samsun province, Türkiye. Turkish JAF Sci Tech, 7(3): 426-434. https://doi.org/10.24925/turjaf.v7i3.426-434.2359.

Aertsens J, Koen MGVH. 2009. Differences in retail strategies on the emerging organic market. Br Food J, 111(2-3): 138-154. https://doi.org/10.1108/00070700910931968.

Ağızan K, Bayramoğlu Z. 2023. Marketing strategies in organic agriculture: Supplier selection criteria and efficiency analysis. J Agric Econ Resour, 9(2): 156-174. https://doi.org/10.61513/tead.1365192.

Arslan B. 2016. Attitudes of consumers living in Şanlıurfa towards organic products. In: 12th National Agricultural Economics Congress, May 25-27, Isparta, Türkiye, pp. 623-631.

Arslantürk Y, Aysen E. 2015. Fair trade and organic food markets: A case of Ankara. Kırıkkale Uni J Soc Sci, 5(1): 15-26.

Ayan AK, Boz I, Kaynakci C, Aytac S. 2017. Suppliers of organic food: Evidence from Sisli and Kartal ecological bazaars of

Istanbul. Inter J Sci Resour Manag, 5: 5553-5559. https://doi.org/10.18535/ijsrm/v5i6.29

Eryılmaz GA, Demiryürek K, Emir M. 2015. Consumer behaviour towards organic agriculture and food products in the European Union and Türkiye. Anadolu J Agric Sci, 30: 199-206. http://doi.org/10.7161/anajas.2015.30.2.199-206.

Chen A, Scott S. 2014. Rural development strategies and government roles in the development of farmers' cooperatives in China. J Agric Food Syst Comm Dev, 4(4): 35-55. https://doi.org/10.5304/JAFSCD.2014.044.005.

Chernbumroong S, Sureephong P, Suebsombut P, Sekhari A. 2022. Training evaluation in a smart farm using Kirkpatrick Model: A case study of Chiang Mai. In: Digital Arts, Media and Technology with ECTI Northern Section Conference on Electrical, Electronics, Computer and Telecommunications Engineering, January 26-28, Chiang Rai, Thailand, pp: 463-466.

Erem KT, Atsan T. 2013. Factors affecting rural women's adoption of organic agriculture (TRA1 of sample). Res Agric Sci, 44(1): 43-49. https://doi.org/10.20289/zfdergi.408821.

Eti HS. 2014. Marketing of organic food and analysis of consumer attitude and behavior towards organic food. Ph.D Thesis, Namık Kemal University, Graduate School of Natural and Applied Sciences, Department of Agricultural Economics, Tekirdağ, Türkiye, pp: 455.

Gifford A, Philemon R, Halbert J, Hothersall EJ, Inglis R, Hart J, Byrne-Davis L, Thirsk J, Gifford H, Howells R, Weetch S, Prentice K, Jackson A, Kirkpatrick M. 2023. A narrative review of course evaluation methods for continuing professional development: The case of paediatric and neonatal acute-care in-service courses in low and lower-middle income countries: BEME Guide No. 76. Med Teach, 45(7): 685-697. https://doi.org/10.1080/0142159X.2022.2137010.

Grimm M, Luck N, Steinhübel F. 2023. Consumers' willingness to pay for organic rice: Insights from a non-hypothetical experiment in Indonesia. Aust J Agric Resour Ec, 67(1): 83-103. https://doi.org/10.1111/1467-8489.12501.

Hauser M, Aigelsperger L, Owamani A, Delve RJ. 2010. Learning achievements of farmers during the transition to market-oriented organic agriculture in rural Uganda. J Agric Rural Dev Trop Subtrop, 111(1): 1-11. http://nbn-resolving.de/urn:nbn:de:hebis:34-2010082734305.

Jaafar M, Jayabalan S, Ramasamy N, Suffarruddin SH. 2022. A four-level agropreneurship training evaluation model for rural communities. J Busin Soc Dev, 10(1): 41-58. http://doi.org/10.46754/jbsd.2022.03.004.

Kaya İ. 2009. Marketing is Unique - A Marketing Encyclopedia / 387 Ways to Touch Your Customer. Babıali Kültür Publishers, İstanbul, Türkiye, pp: 376.

Kaya Y, Günay R, Damgacı FK. 2015. Kirkpatrick's four-level evaluation model. STM J, 2(5): 89-97.

Kirkpatrick DL. 1995. Revisiting Kirkpatrick's four-level model. Train Dev J, 50(1): 54-57.

Kirkpatrick DL, Kirkpatrick DJ. 2007. Implementing the four levels. Berrett Koehler Publishers, Broadway, ABD, pp: 143.

Koday S, Çelikoğlu Ş. 2011. An example of traditional shopping site: Bartin ladies' bazaar (Galla Bazaar). J Grad Sch Soc Sci, 15(2): 243-262.

McLean S, Moss G. 2003. They're happy, but did they make a difference applying Kirkpatrick's framework to the evaluation of a national leadership program. The Canadian J Prog Eva, 18(1): 1-23. https://doi.org/10.3138/cjpe.018.001.

Mignouna DB, Aighewi BA, Maroya N, Akinribido B, Balogun M, Akintayo OT, Amah D, Awotide B, Dontsop Nguezet PM, Abdoulaye T. 2023. Evaluation of training on good agronomic practices for seed yam production in Nigeria. Seeds, 2(1): 116-126. https://doi.org/10.3390/seeds2010009.

Nagnur S, Hosamani V, Shapur A. 2012. Training on organic farming practices for women: An impact study. J Farm Sci, 25(2): 253-255.

Qiao Y, Halberg N, Vaheesan S, Scott S. 2016. Assessing the social and economic benefits of organic and fair trade tea production for small-scale farmers in Asia: A comparative case study of China and Sri Lanka. Renew Agric Food Syst, 31(3): 246-257. https://doi.org/10.1017/S1742170515000162.

Sahni J. 2020. Managerial training effectiveness: An assessment through Kirkpatrick framework. TEM J, 9(3): 1227-1233. https://doi.org/10.18421/TEM93-51.

Stefan H, Mortimer M, Horan B. 2023. Evaluating the effectiveness of virtual reality for safety-relevant training: A systematic review. Virtual Real, 27: 2839–2869. https://doi.org/10.1007/s10055-023-00843-7.

Şahan G, Altaç İ, Yasa HD, Ay F, Şen Ş. 2014. An assessment about the perceptions of the women working in Bartin bazaar of ladies on life through the eyes of educators. Bartın Uni J Fac Edu, 3(2): 416-434. https://doi.org/10.14686/BUEFAD.201428192.

TUIK. 2022. Turkish Statistical Institute (Türkiye İstatistik Kurumu). URL: https://biruni.tuik.gov.tr/medas/?kn=92&locale=tr (accessed date: September 21, 2023)

ZEEMAPS. 2024. ZeeMaps. URL: https://www.zeemaps.com/map?group=4980332&location=Bafra%2C%20Samsun%2C%20TUR&add=1 (accessed date: January 21, 2024).

Black Sea Journal of Agriculture
doi: 10.47115/bsagriculture.1628032

Open Access Journal
e-ISSN: 2618 – 6578

Research Article
Volume 8 - Issue 2 : 251-255 / March 2025

THE EFFECTS OF SEAWEED APPLICATIONS ON THE GERMINATION RATE AND SPEED OF CARROT (*Daucus Carota* Var. *Sativus*) SEEDS UNDER SALT STRESS

Necibe KAYAK[1]*

[1]*Sakarya University of Applied Sciences, Faculty of Agriculture, Department of Horticulture, 54100, Sakarya, Türkiye*

Abstract: In this study, the effects of commercial seaweed extract (Maxicrop®) applications on germination percentage, germination index, and germination time of carrot seeds were investigated under different salt concentrations in laboratory conditions using Petri dishes. The experiments were conducted with 16 different combinations of 4 salt doses (T1: 0 mM, T2: 50 mM, T3: 100 mM, T4: 150 mM) and 4 seaweed extract doses (D1: 0, D2: 1:250, D3: 1:500, D4: 1:1000) in three replicates. According to the results, seaweed extract applications increased germination percentage and shortened germination time. The highest germination percentage was observed in the combinations T2D4 (45.18%) and T2D1 (45.00%), while the lowest was in T4D1 (36.61%). The germination index reached its highest value in the T1D1 (20.80) combination, while the lowest was recorded in T4D1 (7.42). In terms of germination time, the shortest time was observed in T1D1 (1.50 days), and the longest in T4D1 (3.70 days). Increased salt concentration negatively affected germination performance, whereas seaweed extract partially alleviated these effects. It was determined that seaweed applications supported seed metabolism and improved germination under stress conditions through an osmotic priming effect. These findings highlight the positive effects of seaweed-based products on seed germination and support their potential use in agricultural practices.

Keywords: Seaweed extract, Carrot, Germination time, Germination percentage

***Corresponding author:** Sakarya University of Applied Sciences, Faculty of Agriculture, Department of Horticulture, 54100, Sakarya, Türkiye
E mail: necibekayak@subu.edu.tr (N. KAYAK)
Necibe KAYAK https://orcid.org/0000-0001-7104-8544

Received: January 28, 2025
Accepted: March 03, 2025
Published: March 15, 2025

Cite as: Kayak N. 2025. The effects of seaweed applications on the germination rate and speed of carrot (Daucus carota var. sativus) seeds under salt stress. BSJ Agri, 8(2): 251-255.

1. Introduction

Climate change and the world's growing population have exacerbated a number of environmental stress factors that endanger agricultural output. Many plants ideal growing circumstances are upset by abiotic stressors such as high temperatures, droughts, and salinities, which result in large losses in agricultural output (Bray et al., 2000; Rockström and Falkenmark, 2000). Salinity is regarded as one of the most important stressors for agricultural land's sustainability (Altun and Arslan, 2022).

Due to uncontrolled fertilization and irrigation practices, salt problems currently affect about 23% of agricultural lands and 33% of irrigated regions. This percentage is rising quickly. By the mid-twenty-first century, it is projected that 50% of agricultural fields worldwide will face saline stress (Zaman et al., 2018). Salinity restricts plant growth and productivity by negatively influencing basic physiological functions such as seed germination, vegetative growth, and reproductive development (Bolton, 2019).

Plant development is particularly vulnerable to environmental stress during seed germination and early seedling growth (Jones, 1986). By limiting water intake through osmotic potential and negatively impacting embryo viability through ion toxicity, salinity inhibits seed germination (Kaymakanova, 2009). When salt builds up in soil water, the osmotic potential is reduced, which prevents seeds from absorbing water. Furthermore, dry seeds cannot absorb water due to high environmental salt concentrations, specifically sodium (Na^+) and chloride (Cl^-) ions (Uçarlı, 2020). One of the most notable effects of salinity on seed germination is its ability to slow germination rates and, at higher levels, reduce the percentage of germination. At lower concentrations, only the germination rate is affected, with no significant impact on the total percentage of germinated seeds (Shannon and Grieve, 1999). Therefore, studies aimed at understanding plant tolerance to salinity stress are critical for achieving agricultural sustainability.

The Apiaceae family includes the widely grown and extensively consumed carrot (*Daucus carota* L.), a cool-season vegetable (Rubatzky et al., 1999). In terms of market value and area under cultivation, carrots are one of the most commercially important vegetables in the world. Because of their high α- and β-carotene content, which is transformed into retinol (vitamin A), carrots are an essential source of nutrients for immune system support and eye health (Klimek-Chodacka et al., 2015). One of the vegetables most susceptible to salinity is the cultivated carrot (*Daucus carota* var. *sativus*) (Bernstein and Ayers, 1953; Mann et al., 1961). Carrots' ability to withstand salt during the germination stage has not been thoroughly studied up to this point (Schmidhalter and Oertli, 1991; Kahouli et al., 2014).

Vegetable seeds are often subjected to various pre-sowing treatments to ensure optimal germination and emergence under adverse conditions. One such treatment involves soaking seeds in natural osmotic solutions like seaweed extracts (Demirkaya, 2010). According to Shukla et al. (2018), seaweed extracts have several positive impacts, such as better seed germination, greater plant output, improved tolerance to biotic and abiotic stressors, and longer post-harvest seed shelf life. Numerous bioactive substances, including betaines, cytokinins, and auxins, are found in seaweed (Zhang and Ervin, 2008). Therefore, this study aimed to investigate the effects of seaweed extract, an organic material, on seed germination in carrots under saline conditions.

2. Materials and Methods

This study was carried out in the Department of Horticulture laboratory at the Faculty of Agriculture, Sakarya University of Applied Sciences, in 2024. The plant material used in the study was the Nantes Scarlet carrot (*Daucus carota* var. *sativus*) variety, sourced from Bursa Seed Industry Interventional studies involving animals or humans, and other studies that require ethical approval, must list the authority that provided approval and the corresponding ethical approval code.

2.1. Seed Sterilization and Experimental Design

The carrot seeds used in the trials were sterilized by soaking them in a 1% sodium hypochlorite (NaOCl) solution for 5 minutes, followed by rinsing with sterile distilled water to complete the sterilization process. After sterilization, a stock solution of the commercial seaweed extract Maxicrop (*Ascophyllum nodosum*) (Maxicrop USA Inc.) containing plant growth-promoting substances such as cytokinins, auxins, enzymes, amino acids, trace elements, and nutrients (pH: 7.33, EC: 0.75 mS, N: 0.75%, P_2O_5: 0.05%, K_2O: 19.28%) was prepared by dissolving 10 g of the extract in 100 ml of distilled water at a 1:10 ratio. The stock solution was diluted further to prepare solutions with concentrations of 1:250, 1:500, and 1:1000. Seeds were soaked in these prepared solutions at 25±2 °C for 24 hours.

For germination trials, two layers of filter paper were placed in each Petri dish, and 50 carrot seeds were evenly distributed on the paper. Four different salt concentrations (T1:0 mM, T2:50 mM, T3: 75 mM, and T4:100 mM NaCl) were prepared, and 5 ml of the respective solution was added to each Petri dish based on the treatments. The trials were conducted using 16 different combinations of four salt concentrations and four seaweed extract dilutions (D1: 0, D2: 1:250, D3: 1:500, D4: 1:1000) in a completely randomized design with three replicates per treatment (Table 1). The prepared Petri dishes were kept in germination cabinets at 25±2 °C for 10 days (ISTA, 1996).

Table 1. Combinations of salt dose and seaweed extract dose used in the experiments

T1*D1	T2*D1	T3*D1	T4*D1
T1*D2	T2*D2	T3*D2	T4*D2
T1*D3	T2*D3	T3*D3	T4*D3
T1*D4	T2*D4	T3*D4	T4*D4

Each Petri plate was lined with two layers of filter paper, and then 50 seeds were added. NaCl solutions with concentrations of 0 mM, 50 mM, 75 mM, and 100 mM were made for the salt treatments, and 5 ml of each solution was added to each Petri dish in accordance with the treatments.

The Petri dishes were checked every 24 hours, and the number of germinated seeds was counted. The counting continued until the 10th day. The germinated seeds were removed from the environment for counting, and the data was recorded.

2.2. Evaluated Traits and Calculations

Germination Rate (%): The number of germinated seeds was counted on the 10th day, and the germination rate was calculated using the following formula:

Germination Rate (%)=(Number of Germinated Seeds /Total Number of Seeds)×100 (Yıldırım and Güvenç, 2005).

Germination Index (GI): The daily number of germinated seeds (Gi) was divided by the corresponding day number (Tt), and the total of these values was calculated:

$GI = \Sigma(Gi / Tt)$ (Wang et al., 2004).

Mean Germination Time (MGT): The sum of the products of the number of germinated seeds (f) and the corresponding days (x) was divided by the total number of germinated seeds:

$MGT = \Sigma(fx) / \Sigma f$ (Ellis and Roberts,1980).

2.3. Statistical Analysis

The research data were analyzed using the *JUMP* 13 software program (SAS Institute, Cary, NC, USA). Parameters such as germination rate, germination index, and mean germination time were evaluated using two-way analysis of variance (Two-Way ANOVA). The statistical significance of factors and their interactions was examined at a 5% significance level. LSMeans Differences the Tukey HSD test was used for comparison (SAS Institute, Cary, NC, USA). In the analyses of germination percentages, arc Sin p 1/2 angular transformation values were used.

3. Results

The results of the germination trials, including the effects of seaweed extract applications on carrot seed germination rates under different salt concentrations, are presented in table 2. Germination rates were generally highest on the first day. The average germination rate across all treatments was around 10–11 seeds, indicating that the seeds quickly absorbed water and began germinating. The control group (0 mM NaCl) and the 1:500 seaweed extract application showed the highest germination rates on the first day. As the days progressed, germination rates decreased across all treatments. Notably, after the fourth day, a significant decline in germination rates was observed, indicating that most of the germination occurred within the first few days.

Table 2. Effects of seaweed applications under saline conditions on germination percentage, index, and duration of nantes scarlet carrot variety

	Treatments	Germination Percentage	Germination Index	Germination Duration
	Saline Applications			
	T1	43.17 a	18.62 a	18.62 a
	T2	43.00 a	16.66b	16.66 b
	T3	42.65 a	16.27b	16.27 b
	T4	39.07 a	11.04c	11.04 c
	Seaweed Applications			
	D1	41.61 a	13.97 b	16.11 a
	D2	41.05 a	16.11 a	13.97 b
	D3	42.28 a	16.18 a	16.18 a
	D4	42.95 a	16.33 a	16.33 a
	T X D (Interactions)			
T1	D1	43.46 ab	20.80 a	1.50 g
	D2	43.23 ab	17.00 abcde	1.72 efg
	D3	42.68 ab	17.70 abcd	1.62 fg
	D4	43.30 a	18.98 ab	1.87 defg
T2	D1	45.00 ab	18.66 abc	2.23 cde
	D2	40.37 ab	13.89 def	2.13 cdef
	D3	40.05 ab	14.92 bcde	1.92 cdefg
	D4	45.18 ab	19.18 ab	1.82 defg
T3	D1	41.38 ab	17.55 abcd	1.91 cdefg
	D2	43.46 ab	15.27 bcde	2.0 cdefg
	D3	44.72 ab	18.07 abcd	1.96 cdefg
	D4	42.43 ab	14.21cdef	2.35 bcd
T4	D1	36.61 b	7.42 g	3.70 a
	D2	37.13 ab	9.74 fg	2.80 b
	D3	41.66 ab	14.05 def	2.43 bc
	D4	40.87 ab	12.95 ef	2.43 bc
	Significance			
	Salt doses	0.1793	<.0001*	<0.0001*
	Seaweed extract	0.8174	0.0014*	0.0823
	T X D (Interactions)	0.8354	<0.0001*	0.0036*

T1= 0, T2= 50, T3= 75, T4= 100 Mm NaCl; D1= 0, D2= 1:250, D3= 1:500, D4= 1:1000 seaweed applications

Statistical differences were found for the germination index and germination time of carrot seeds under different salt concentrations (Table 2). As salt concentration increased, the germination index decreased significantly. The germination index in T1 was 18.62, while it dropped to 11.04 in T4. Similarly, germination time increased as salt concentration increased. The value in T1 was 18.62, while it was 11.04 in T4. The salt doses did not have a statistically significant effect on germination percentage; however, as salt concentration increased, germination percentage decreased (Table 2).

Regarding the effect of seaweed extract on carrot seed germination, statistical differences were found for both the germination index and germination time (Table 2). Seaweed extract did not have a statistically significant effect on the germination percentage. When examining the effect on the germination index, the D1 treatment (13.97) showed a slightly lower index compared to other treatments. There were no significant differences between D2, D3, and D4 treatments. The germination time was shorter in D2 (13.97) compared to other treatments, where it ranged between 16.11 and 16.33 days. The D2 treatment shortened the germination time, allowing the seeds to germinate faster than other treatments.

When evaluating the interaction between different salt concentrations and seaweed extract applications (T*D), the highest germination percentage was observed in the T2D4 (45.18%) and T2D1 (45.00%) combinations. The lowest germination percentage was observed in the T4D1 (36.61%) combination. The highest germination index was measured in the T1D1 (20.80) combination, while the lowest germination index was found in the T4D1 (7.42) combination. As salt concentration increased (T4), the germination index showed a significant decline. However, seaweed extract applications, especially in the T1 and T2 groups, maintained a high index. The shortest germination time was observed in the T1D1 (1.50 days) combination, demonstrating the positive effects of both low salt concentration and seaweed extract. The longest germination time was found in the T4D1 (3.70 days) combination, highlighting the negative impact of high salt concentration (Table 2).

4. Discussion and Conclusion

Ensuring tolerance to external challenges at the crucial initial stage of plant development, seed germination, is essential. In this study, applying seaweed extract to carrot seeds considerably boosted their rate and speed of germination in saline circumstances as compared to the control, and it also lessened the adverse effects of salinity stress. The treatments with seaweed extract worked very well at moderate dosage (1:250 and 1:500). Although there was an early favorable effect at lower doses (1:1000), no discernible contribution was noted in the days that followed (Table 2).

Osmotic conditioning with seaweed extract has been reported in several studies to increase germination rate and shorten germination time (Sivritepe, 2000; Yıldırım and Güvenç, 2005; Demirkaya, 2010). The natural growth regulators (such as hormonal compounds, amino acids, and micronutrients) and antioxidant properties contained in seaweed extracts can support seed metabolism, improving germination even under stress conditions (Demirkaya, 2010). The shorter the average germination time for a group of seeds, the higher the germination potential of that seed group. As the average germination time increases, the seed group’s strength decreases. Osmotic conditioning with seaweed extract reduced both germination time and enhanced germination in carrot seeds.

Möller and Smith (1998) found that applying seaweed extract to lettuce seeds for 24 hours positively affected germination under both normal and high temperatures. In other study on leeks, Yıldırım and Güvenç (2005) observed that 1:250 and 1:500 seaweed extract concentrations significantly improved both germination rate and germination index compared to other treatments. A study conducted by Demirkaya (2010) demonstrated that osmotic conditioning with seaweed extract increased the germination rate and reduced average germination time in pepper and onion seeds.

Based on the results of this study, it is recommended to soak carrot seeds in seaweed extract or water for 24 hours before planting to enhance germination rate and speed under both salt stress and normal conditions. Given that osmotic conditioning with seaweed extract is an organic, environmentally friendly substance that does not cause pollution, its use is recommended to minimize the reliance on chemicals.

Author Contributions

The percentages of the author’ contributions are presented below. The author reviewed and approved the final version of the manuscript.

	N.K.
C	100
D	100
S	100
DCP	100
DAI	100
L	100
W	100
CR	100
SR	100
PM	100
FA	100

C= concept, D= design, S= supervision, DCP= data collection and/or processing, DAI= data analysis and/or interpretation, L= literature search, W= writing, CR= critical review, SR= submission and revision, PM= project management, FA= funding acquisition.

Conflict of Interest

The author declared that there is no conflict of interest.

Ethical Consideration

Ethics committee approval was not required for this study because there was no study on animals or humans.

References

Altun M, Arslan H. 2022. Effects of salinity on yield, yield components and water productivity of black carrot (*daucus carota* l.) under water stress condition. YY Univ J Agri Sci, 32 (1): 106-118.

Bernstein L, Ayers A. 1953. Salt tolerance of five varieties of onions. Proceed American Soc Horticult Sci, (62): 367-370.

Bolton AL. 2019. Evaluating salt and heat tolerance in diverse germplasm of carrot (*Daucus carota* L.). PhD thesis, The University of Wisconsin, Madison ProQuest Dissertations, Madison, USA, pp: 215.

Bray TM. 2000. Dietary antioxidants and assessment of oxidative stress. Nutr, 16(7-8): 578-581.

Demirkaya M. 2010. Deniz yosunu (Ascophyllum nodosum) ekstraktı uygulamalarının biber ve soğan tohumlarının canlılığı ve gücüne etkileri. Erciyes Üniv Fen Bilim Enstit Derg, 26 (3): 217-224.

Ellis R, Roberts E. 1980. Towards a rational basis for testing seed quality. Butterworths, London, UK, pp: 605-635.

ISTA. 1996. International seed testing association. https://www.seedtest.org/en/home.html (accesed date: March 14, 2024).

Jones R. 1986. High salt tolerance potential in Lycopersicon species during germination. Euphytica, 35: 576–582.

Kahouli B, Borgi Z, Hannachi C. 2014. Study of the tolerance of ten accessions of carrot (*Daucus carota* L.) to salinity. J Stress Physiol Biochem, 10 (3): 18-27.

Kaymakanova M. 2009. Effect of salinity on germination and seed physiology in bean (*Phaseolus vulgaris* L.). Biotechnol Equipment, 23(sup1): 326-329.

Klimek-Chodacka M, Sadłowska K, Grzebelus D, Barański R. 2015. Carrot seed germination and plant growth in salt stress condition. XIV Overall Polish in vitro Culture and Plant Biotechnology Conference, 14-19 September, Poznań, Poland, pp: 111.

Mann L, Little T, Sims W. 1961. Growing garlic in California. Publications University Calif. Agricultural Ext. Service, New York, USA, pp: 63.

Möller M, Smith M. 1998. The applicability of seaweed suspensions as priming treatments of lettuce (*Lactuca sativa* L.) seeds. Seed Sci Technol, 26: 425-438.

Rockström J, Falkenmark M. 2000. Semiarid crop production from a hydrological perspective: gap between potential and actual yields. Critical Rev Plant Sci, 19(4): 319-346.

Rubatzky V, Quiros C, Simon P. 1999. Carrots and related vegetable Umbelliferae. Wageningen publishing, Wageningen, Netherlands, pp: 142.

Schmidhalter U, Oertli J. 1991. Germination and seedling growth of carrots under salinity and moisture stress. Plant Soil, 132: 243-251.

Shannon MC, Grieve CM. 1999. Tolerance of vegetable crops to salinity. Sci Horticultur, 78: 5-38.

Shukla PS, Shotton K, Norman E, Neily W, Critchley AT, Prithiviraj B. 2018. Seaweed extract improve drought tolerance of soybean by regulating stress-response genes. AoB Plants, 10(1): plx051.

Sivritepe H. 2000. Deniz yosunu ekstrakti (*Ascophyllum nodosum*) ile yapilan ozmotik koşullandirma uygulamalarinin biber tohumlarinda canlilik üzerine etkileri. III, Sebze Tarımı Sempozyumu, 21-23 Eylül, İzmir, Türkiye, ss: 11-13.

Uçarlı C. 2020. Effects of salinity on seed germination and early seedling stage. Abiotic Stress Plants, 211: 10.5772.

Wang Y, Yu L, Nan Z, Liu Y. 2004. Vigor tests used to rank seed lot quality and predict field emergence in four forage species. Crop Sci, 44(2): 535-541.

Yıldırım E, Güvenç İ. 2005. Deniz yosunu özü uygulamalarinin tuzlu koşullarda pirasada tohum çimlenmesi üzerine etkisi, BAHÇE, 34(2): 83-87.

Zaman M, Shahid SA, Heng L, Shahid SA, Zaman M, Heng L. 2018. Soil salinity: Historical perspectives and a world overview of the problem. Springer, London, UK, pp: 43-53.

Zhang X, Ervin EH. 2008. Impact of seaweed extract-based cytokinins and zeatin riboside on creeping bentgrass heat tolerance. Crop Sci, 48: 364-370.

Black Sea Journal of Agriculture
doi: 10.47115/bsagriculture.1634183

Open Access Journal
e-ISSN: 2618 – 6578

Research Article
Volume 8 - Issue 2 : 256-262 / March 2025

THE EFFECTS OF AGRICULTURAL MONITORING AND INFORMATION SYSTEM ON PRODUCERS

Kerem HAZNECİ[1]*, Esin HAZNECİ[1]

[1]*Ondokuz Mayıs University, Faculty of Agriculture, Department of Agricultural Economics, 55139, Samsun, Türkiye*

Abstract: The aim of this study is to evaluate the effects of Agricultural Monitoring Information System (TARBIL) on producers and their opinions about TARBIL. Questionnaires were administered to 105 farmers in 19 Mayıs district of Samsun province about their internet usage habits, access to information and evaluation of Agricultural Monitoring Information System. The effectiveness of information management systems in agriculture was tried to be determined by identifying farmers' opinions about TARBIL, a producer-based analysis was made. In general, it was observed that farmers have an awareness towards TARBIL system. However, it was concluded that farmers face some obstacles in using the system and therefore the need for training is evident. Although farmers' attitudes towards the use of technology are generally positive, it was also determined that there is a need for more ease of access and training support for the effective use of applications. Study results revealed that the views that the internet can influence farmers' production decisions received lower scores and farmers' lack of equipment and competence in computer and internet use showing that farmers have difficulties both in entering data into the system accurately and regularly and in accessing technology. TARBIL is considered to be very important for food safety, environmental and economic sustainability of agricultural production. From this point of view, the importance of making new regulations and further development of the system for the effective and efficient use of TARBIL system is once again understood.

Keywords: Agricultural monitoring and information system, TARBIL, Agricultural information management, Samsun, Türkiye

***Corresponding author:** Ondokuz Mayıs University, Faculty of Agriculture, Department of Agricultural Economics, 55139, Samsun, Türkiye
E mail: kerem.hazneci@omu.edu.tr (K. HAZNECİ)
Kerem HAZNECİ https://orcid.org/0000-0002-2567-1260
Esin HAZNECİ https://orcid.org/0000-0002-8695-028X

Received: February 05, 2025
Accepted: March 03, 2025
Published: March 15, 2025

Cite as: Hazneci K, Hazneci E. 2025. The effects of agricultural monitoring and information system on producers. BSJ Agri, 8(2): 256-262.

1. Introduction

Agricultural Monitoring and Information System (TARBIL), it is an integrated system in which the country's agriculture is recorded in every field with satellites, stations and field personnel, data are kept, reporting is made and the results are observed. TARBIL is the collection of all kinds of agricultural activities, agricultural data, agricultural lands, human and physical real coordinates in a common database (UTGB, 2021). It is a system for performing various analyses on the data according to the purpose and displaying the results in the form of tables, graphs and maps. TARBIL is primarily a system created to record agricultural lands, to observe agricultural production within the system, to predict efficiency and yield, to determine the right investment and the right strategies. In addition, it also aims to develop national policies, control and follow-up of products and production, ensure food security, protect natural resources and ensure sustainability (Anonymous, 2024). TARBIL Project was initiated in 2008 as a 3-year project under the name of 'Agricultural Yield Forecasting and Drought Monitoring (TARIT)'. Later on, the scope of the project was developed and a protocol was signed between the Ministry of Agriculture and Forestry, Turkish Statistical Institute (TURKSTAT), Istanbul Technical University Rectorate on 31.10.2011 and TARBIL project entered into force. It is a system created by integrating 42 databases such as enterprise registration, animal registration, parcel registration, agricultural inputs database, milk database and organic agriculture database (Anonymous, 2009).

TARBIL is based on two main pillars; the first pillar is the production and use of accurate, instantaneous data. Data is obtained by taking live images with cameras from 400 stations, which have already been completed, where 39 different parameters such as wind speed, humidity, climatic conditions, soil temperature are recorded. The most important feature of the system and the most different feature compared to its equivalents is that the need can be determined according to the developmental stage of the plants. The second pillar is the Agriculture Information System (AIS), which also includes mobile applications. TBS is a system in which data, information, documents and processes belonging to all agricultural activities throughout Türkiye are grouped according to the types of activities, where follow-up is provided, all institutional authorisation and auditing processes can be carried out, and data dumps of all relevant processes are followed in an integrated manner (Anonymous, 2019). By mixing small and meaningless data obtained from producers in agriculture with other components such as climate data, satellite images, databases and agricultural observations, TBS obtains data suitable for agricultural planning by drawing a meaningful model adapted to the whole country (Anonymous, 2024). Due to the increases in population, it became a necessity to obtain the maximum yield from the unit area in the agricultural sector due to the limited resources, gradual decrease in agricultural land, and the constant change in climatic conditions. TARBIL is of great importance for the Turkish farmer to be more successful, for the country's agriculture to reach an advanced level, to ensure the supply-demand balance by keeping the pulse of the market, to determine agricultural policies and for the development of the country (Gürbüz and Bayar, 2018).

Studies concerning the research topic, knowledge and knowledge management (Akgün and Keskin, 2003; Tonta, 2004; Odabaş, 2005; Güçlü and Sotirofski, 2006; Atılgan, 2009; Müderrisoğlu, 2012; Selvi, 2012), the use of knowledge management in agriculture and other sectors (Güler and Kara, 2005; Erdal and Çallı, 2013; Atalay, 2017; Mercan et al., 2017; Tunç et al., 2017; Özğan, 2017; Gülter et al., 2018; Altıntaş, 2019) and evaluating TARBİL and TBS in terms of agricultural engineers and technicians (Bayar, 2019) are abundant in the literature. Although there are studies on knowledge management, information technologies, and internet usage of farmers in Türkiye, no studies on TARBIL and TBS at farmer level, which makes this study as a unique were not found in the literature. With this study, it is aimed to reveal the characteristics that determine the internet usage tendencies of the farmers in 19 Mayıs district of Samsun province and how effectively they use TARBIL. With the research, it is also aimed to develop suggestions for the use of TARBIL and TBS.

2. Materials and Methods

The main material of the study consisted of primary data obtained from surveys conducted with farmers engaged in agricultural production in 38 neighbourhoods in 19 Mayıs district of Samsun province. The questionnaires were applied in August and September 2022. In addition, secondary data obtained from published articles, books, research reports, theses, Ministry of Agriculture and Forestry, TURKSTAT, etc. on the subject were also used.

The main sample of the research consisted of 1650 enterprises engaged in agricultural production in 19 Mayıs district of Samsun Province. Simple random sampling method was used to determine the number of enterprises to be surveyed. In the sampling process, the margin of error allowed for the average was accepted as 10% and 95% confidence level was used. The number of enterprises to be surveyed was determined as 91 with the help of the formula given below (Yamane, 2001). However, just in case, 15% of the participants were also included to the study. Therefore, a total of 105 producers, 60 from the central neighbourhood and 45 from other neighbourhoods, representing each neighbourhood from 38 neighbourhoods in 19 Mayıs district of Samsun province, were included in the study.

$$n = \frac{N(zS)^2}{Nd^2 + (zS)^2} \quad (1)$$

In the equation 1; n is the number of enterprises to be surveyed, N is the number of enterprises in the main population, S is the standard deviation and d is the margin of error allowed in the research.

SPSS statistical package programme was used in the evaluation and analysis of the data collected at the end of the research. Descriptive statistics consisting mainly of mean, standard deviation, frequency and percentages were used in the study Farmers' opinions and awareness levels about TARBIL were tried to be determined by using a five-point Likert scale. For example, for each question prepared to determine the level of TARBIL usage, farmers responded on a five-point Likert scale as follows; 1: Strongly disagree, 2: Disagree, 3: No opinion, 4: Agree 5: Strongly agree. The following interpretation scale was used to interpret the averages (Palaz and Boz, 2008). Mean between 1.00-1.49 = Strongly Disagree (SD), between 1.50-2.49 = Disagree (D), between 2.50-3.49 = No Opinion (NO), between 3.50-4.49 = Agree (A) and between 4.50-5.00 = Strongly Agree (SA).

3. Results and Discussion

Approximately 76% of the farmers participating in the study were male and 24% were female. The fact that the majority of the farmers were male in the interviews conducted in the research area is due to the fact that men take an active role in agricultural production in 19 Mayıs district of Samsun province. While the average age of the farmers was 45.53 years, the average age of male farmers was found to be approximately 46 years and 43 years for female farmers. Approximately 65 percent of the farmers are high school or university graduates. 51 percent of the interviewed farmers are engaged in farming only. Approximately 49 percent of the farmers work in the public or private sector and also farm at the same time. The average land size of the farmers is 22.47 decares (Table 1).

In the examination of the internet usage habits of the farmers, mobile phone was found to be to be the most common device used for internet access. While 68.79% of the participants use mobile phones, other devices such as desktop computers (24.11%) and laptops (4.26%) are less preferred (Table 2).

Table 1. Socio-demographic characteristics of the farmers

		Frequency (%)	Mean (SD)
Gender	Male	80.00 (76.19)	-
	Female	25.00 (23.81)	-
	Total	105.00 (100.00)	-
	Male	-	46.46 (11.75)
Age	Female	-	42.56 (8.86)
	Total	-	45.53 (11.21)
Education	Primary school	6 (5.71)	-
	Middle school	28 (26.67)	-
	High school	34 (32.38)	-
	Licence	34 (32.38)	-
	Postgraduate	3 (2.86)	-
	Total	105 (100.00)	-
Employment status	Public institution	24 (22.86)	-
	Private sector	27 (25.71)	-
	Farmer	54 (51.43)	-
	Total	105 (100.00)	-
Land size (da)		-	22.47 (19.78)

Tor and Erden (2004), in their study on the use of social media and computers by farmers, concluded that computer use at home increased as the level of education increased. While 39.45% of the farmers use the internet between 1-3 hours daily, 32.28% of them go online for less than 1 hour. In terms of the purpose of internet use, the most common activities are communication (23.63%) and following the news (22.14%). Functional purposes of using internet such as search for information and banking transactions also occupy an important place, while socialising and entertainment purposes are less common (Table 2).

Table 3 reveals the farmers' views on TARBIL system and their awareness of this system. While 93.33% of the farmers are aware of the TARBIL system, 6.67% are unaware of this system (Table 3).

Table 2. Internet usage habits of farmers

		Frequency	(%)
Farmers' means of access to the internet*	Desktop computer	34	24.11
	Laptop computer	6	4.26
	Mobile phone	97	68.79
	Tablet	4	2.84
	Total	141	100.00
Distribution of the time farmers spend on the internet	Less than 1 hour	34	32.28
	1-3 hours	41	39.45
	3-5 hours	16	15.24
	5-7 hours	8	7.32
	7 hours and over	6	5.71
	Total	105	100.00
Distribution of farmers according to their purpose of using the internet*	Contact	95	23.63
	Following the news	89	22.14
	Search for Information search	73	18.16
	Banking transactions	68	16.92
	Socialisation	60	14.93
	Game / Entertainment	17	4.23
	Total	402	100.00

*More than one answer was given.

In a study conducted to determine the opinions of the personnel working in Bursa Provincial Directorate of Agriculture and Forestry on TARBIL, it was determined that 99% of the participants had heard of TARBIL (Bayar, 2019). While 78.57% of farmers define TARBİL as a ‘farmer information system’, 12.24% consider it as a ‘system for informing politicians’ and 9.19% as a ‘system for agricultural engineers’. In terms of usage, 67.62 per cent of the farmers use TARBIL, while 32.38 per cent do not. 52.20% of the farmers find the system useful primarily for farmers. The others believe that it will benefit agricultural engineers (24.18%) and politicians

(17.58%). Farmers stated that the main factors limiting their access to TARBIL were lack of time (64.35%) and the complexity of the website (35.65%). This finding is supported by the results of the study conducted by Erdal and Çallı (2013) on the factors affecting the way of using the internet. In the study, it was concluded that approximately 84% of the farmers wanted training on the use of TARBIL (Table 3).

Table 3. Farmers' opinions about TARBIL system

		Frequency	(%)
Farmers' awareness of the TARBIL system	Yes	98	93.33
	No	7	6.67
	Total	105	100.00
Farmers' opinions on TARBIL	Farmer information system	77	78.57
	A system for informing politicians	12	12.24
	Agricultural engineer system	9	9.19
	Total	98	100.00
TARBIL usage status of farmers	Yes	71	67.62
	No	34	32.38
	Total	105	100.00
Farmers' views on who will benefit from TARBIL*	Farmers	95	52.20
	Politicians	32	17.58
	Agricultural Engineers/Technicians	44	24.18
	Research organisations	11	6.04
	Total	182	100.00
Factors limiting farmers' access to TARBIL*	Lack of time	74	64.35
	Complexity of the website	41	35.65
	Total	115	100.00
Would you like to be trained about the use of TARBIL?	Yes	88	83.81
	No	17	16.19
	Total	105	100.00

*More than one answer was given.

According to the scale created about the factors affecting the use of information processing systems and TARBIL by farmers, farmers strongly agree with one of the 17 factors included in the research, agree with 5 of them, disagree with 2 of them and remain undecided for 9 factors. As a result of the research, it was concluded that farmers strongly agreed that the Internet facilitates their lives (4.590) and that searching for information on the Internet is enjoyable (4.314). In addition, farmers stated that they can access the information they are looking for quickly (4.305). However, farmers have concerns about the adequacy of the information obtained from the internet (3.943) and their preference for the internet compared to other sources (3.914), but they have concerns about the security and accuracy of agricultural information. Farmers' views on the benefits of TARBIL implementation on agricultural supports and risks are complex. The high number of 'No Opinion' responses indicates that there is no clear opinion on the effectiveness of TARBIL. The views that the Internet can influence farmers' production decisions received lower scores (2.533), and farmers' lack of equipment (2.581) and competence (2.400) in the use of computers and the Internet were also observed. This shows that farmers have difficulties in entering data into the system accurately and regularly (2.229) and have difficulties in accessing technology (Table, 4).

In the study, it was observed that the farmers agreed with all 10 factors that included the opinions of the farmers using TARBIL system about the system (Table 5). The farmers participating in the research believe that TARBIL provides significant advantages to them and that registering to the system does not create a disadvantage (4.156). In addition, they think that TARBIL helps farmers to obtain information about supports and production related issues (4.141). Farmers agree that TARBIL has positive effects on crop and animal production (4.125) and that it is a system that facilitates their work (4.109). The opinions that TARBIL is a necessary tool for producers to act in a systematic way (4.109) and that it plays an important role in the registration of farmers (4.047) are also high. However, issues such as the frequency of updating the data provided by TARBIL (3.938) and whether the data are sufficient to meet user needs (3.828) received slightly lower scores. Regarding trust in TARBIL data (3.797), it was concluded that farmers have some hesitation about the accuracy of the system (Table 5).

Table 4. Factors affecting farmers' use of information processing systems and TARBIL

n=105	Mean	SD	Participation Category
The Internet makes my life easier.	4.590	0.583	SA
It is enjoyable for me to search for information on the internet.	4.314	0.684	A
I can access the information I am looking for on the internet without spending much time.	4.305	0.722	A
The information obtained from the internet about production is sufficient.	3.943	0.897	A
I prefer doing research on the internet to doing research from other sources.	3.914	0.962	A
Device and internet ownership will put additional burden on farmers	3.514	1.136	A
With TARBIL, agricultural supports will be able to reach farmers very quickly.	3.257	1.152	NO
Agricultural risks will be minimised with TARBIL.	3.219	1.185	NO
Thanks to TARBIL data, farmers will be able to make agricultural planning.	3.124	1.182	NO
Farmers will have to pay more taxes if all their information is given.	3.105	1.200	NO
Thanks to TARBIL, agricultural products will be sold at the value they deserve.	2.990	1.213	NO
I can access specialised information about farming and production on the internet.	2.667	1.504	NO
Farmers can use devices such as computers/tablets/mobile phones	2.581	1.598	NO
Information about production obtained from the internet is reliable.	2.552	1.500	NO
Information obtained from the internet is effective in making decisions about production.	2.533	1.448	NO
Farmers have internet to enter and follow the data.	2.400	1.504	D
Farmers enter data into the system accurately and regularly.	2.229	1.361	D

Table 5. Opinions of farmers using TARBIL system about the system

n=71	Mean	SD	Participation Category
There is no disadvantage for me whether registered in the TARBIL system or not.	4.156	0.718	A
TARBIL helps me to have an idea about the supports I will receive.	4.141	0.639	A
TARBIL has positive effects on crop and animal production.	4.125	0.724	A
TARBIL is a system that facilitates the work of farmers.	4.109	0.737	A
As a producer, we need TARBIL to act systematically.	4.109	0.838	A
TARBIL is necessary for the registration of farmers.	4.047	0.785	A
I can access information that I cannot access elsewhere through TARBIL.	3.953	0.825	A
TARBIL data are regularly updated.	3.938	0.794	A
TARBIL data is sufficient to meet the needs of users.	3.828	1.001	A
I can trust TARBIL data.	3.797	0.800	A

As a result of the research, it was found that farmers in younger age groups had a higher rate of knowledge about TARBIL, and this rate decreased with age. These results show that young farmers are more prone to technology. In all age groups, the number of farmers who do not have information about TARBIL is limited (7 people). This shows that TARBIL system has a wide awareness level (Table 6).

As it can be seen from the cross tab table, farmers in the 36-45 age group and 46-55 age group use TARBIL more actively. However, the rate of TARBIL usage decreases significantly in higher age groups. As a result, it is seen that the use of TARBIL decreases as the age group increases. While young farmers use TARBIL much more because they are more technologically inclined, the rate of use decreases significantly in older farmers. The table also shows that a total of 34 farmers do not use TARBIL, but it can be said that TARBIL use is widespread (Table 7).

Table 6. Cross-tab link between age and farmers' awareness of TARBIL system

	Have you heard of TARBIL?	Yes	No	Total
Age	18-35	18	1	19
	36-45	32	3	35
	46-55	30	1	31
	56-65	12	2	14
	Over 65 years old	6	0	6
Total		98	7	105

Table 7. Cross-tab link between age and farmers' use of TARBIL

	Do you use TARBIL?	Yes	No	Total
Age	18-35	12	7	19
	36-45	27	8	35
	46-55	23	8	31
	56-65	6	8	14
	Over 65 years old	3	3	6
Total		71	34	105

As a result of the cross table, it is seen that the rate of being aware of TARBIL system increases as the level of education increases. In total, 98 out of 105 farmers stated that they had information about TARBIL, while only 7 farmers stated that they did not have any information about this system. These findings show that the level of education plays an important role in obtaining information about TARBIL system and more educated farmers are more likely to be aware of such systems (Table 8).

Table 8. Cross-tab link between education and awareness of TARBIL system

Have you heard of TARBIL?	Yes	No	Total
Primary school	4	2	6
Middle school	26	2	28
High school	32	2	34
Licence	33	1	34
Postgraduate	3	0	3
Total	98	7	105

As a result of the cross table between education and TARBIL usage status, it is seen that as the level of education increases, the rate of TARBIL usage also increases. While 71 of the farmers use TARBIL, 34 of them do not use it. From this table, it can be clearly stated that the level of education is a factor that increases the use of TARBIL. This result reflects the positive relationship between education level and technology use (Table 9).

Table 9. Cross-tab link between education and TARBIL usage status

Do you use TARBIL?	Yes	No	Total
Primary school	3	3	6
Middle school	16	12	28
High school	24	10	34
Licence	26	8	34
Postgraduate	2	1	3
Total	71	34	105

4. Conclusion

The results of the study revealed that the participants were generally in the middle age group, the majority of them were male farmers, their education levels were distributed in a wide range and their land sizes varied. As a result of the research, it was found that farmers use the internet mostly for functional and practical purposes, especially for communication and information. This situation shows that the role of digital technologies in agricultural activities is gradually increasing. When farmers' views on TARBIL were analysed, it was seen that farmers have a general awareness of TARBIL system. However, it was concluded that farmers encountered some obstacles in use and therefore the need for training is evident. Although farmers' attitudes towards the use of technology are generally positive, it has been determined that more ease of access and training support is needed for the effective use of applications. Farmers using TARBIL system generally evaluate the system in a positive way. However, they think that factors such as data security and frequency of updates should be improved. It was also found that the awareness level of the farmers participating in the research about TARBIL system is high. As a result of the study, it was concluded that younger and middle-aged farmers and farmers with higher education level use TARBIL more actively.

TARBIL is considered to be very important for food safety, environmental and economic sustainability of agricultural production. From this point of view, the importance of new regulations and further development of the system for the effective and efficient use of the TARBIL system is once again understood. In addition to the development of the system, training programmes should be organised at farmer level to enable farmers to use the system more effectively. In this study, although positive results were obtained about the TARBIL system, it was determined that some of the agricultural producers were hesitant about their distrust of the digital environment and the complexity of the internet environment. It is very important for farmers to adapt to the digital environment. For this reason, trainings should be given and seminars should be organised periodically in order for agricultural producers to gain sufficient skills in the internet and digital environment. It is also recommended that more extension work should be carried out in order for farmers to be aware of innovations. The Ministry of Agriculture and Forestry and Provincial Directorates and District Directorates should increase agricultural production publications on their web pages and help producers to access TARBIL format more easily.

Author Contributions

The percentages of the authors' contributions are presented below. All authors reviewed and approved the final version of the manuscript.

	K.H.	E.H.
D	50	50
DCP	50	50
DAI	50	50
L	50	50
W	50	50
CR	50	50
SR	50	50

D= design, DCP= data collection and/or processing, DAI= data analysis and/or interpretation, L= literature search, W= writing, CR= critical review, SR= submission and revision.

Conflict of Interest

The authors declared that there is no conflict of interest.

Ethical Consideration

Ethical approval was obtained from the Ondokuz Mayıs University Social and Human Sciences Ethics Committee (approval date: March 17, 2020, protocol code: 2020 / 765).

References

Akgün EA, Keskin H. 2003. Sosyal bir etkileşim süreci olarak bilgi yönetimi ve bilgi yönetim süreci. GÜ İİBF Derg, 5(1): 175-188.

Altıntaş AS. 2019. Research on the farmers' tendency to use social media: A case of study İzmir. MSc thesis, Ege University, Institute of Science, İzmir, Türkiye, pp: 39.

Anonymous. 2009. TARBİL hakkında bilgiler. URL: https://www.tarnet.com.tr/blog/nedir/tarimsal-izleme-ve-bilgi-sistemi-tarbil/ (accessed date: July 21, 2024).

Anonymous. 2019. TARBİL. URL: http://www.tarbil.gov.tr (accessed date: October 23, 2024).

Anonymous. 2024. URL: https://www.tarimorman.gov.tr/Belgeler/Duyurular/TBS.pdf (accessed date: December 18, 2024).

Atalay E. 2017. the research on social media usage habits of special provincial administration employees: The case of Batman provincial administration, MSc thesis, Afyon Kocatepe University , Institute of Science, Afyon, Türkiye pp: 85.

Atılgan D. 2009. Bilgi yönetimi kavramı ve gelişimi. Türk Kütp Derg, 23(1): 201-212.

Bayar F. 2019. Information management system in agriculture and TARBİL. MSc thesis, Uludağ University, Institute of Science, Bursa, Türkiye pp: 86.

Erdal G, Çallı A. 2013. Çiftçilerin bilgisayar ve internet kullanımına ilişkin bir araştırma: Denizli İli Çivril İlçesi örneği. Gaziosmanpaşa Bil Araş Derg, 8: 71-81.

Güçlü N, Sotırofskı K. 2006. Bilgi yönetimi. Türk Eğt Bil Derg, 4(4): 351-371.

Güler M, Kara T. 2005. Hassas uygulamalı tarım teknolojisine genel bir bakış. Anadolu Tar Bil Derg, 20(3): 111.

Gülter S, Yıldız Ö, Boyacı M. 2018. Çiftçilerin bilgi ve iletişim teknolojilerini kullanma eğilimleri: İzmir ili Menderes ilçesi örneği. Tar Eko Derg, 24(2): 131-143.

Gürbüz İB, Bayar F. 2018. Information management system services from the user's perspective: TARBİL. Turk Stud, 13(13): 23-36.

Mercan Y, Yılmaz E, Sezgin F, Ünal BH. 2017. Tarımsal işletme yeri seçiminde coğrafi bilgi sistemi destekli çok ölçütlü karar analizi uygulamaları. Gaziosmanpaşa Bil Araş Derg, 6: 88-102.

Müderrisoğlu AK. 2012. Assessing usage and effectiveness of knowledge management technologies and techniques. MSc thesis, İstanbul University, Institute of Science, İstanbul, Türkiye, pp: 127.

Odabaş H. 2005. Bilgi yönetimi sistemi. Editörler: Aktan CC, Vural İY. Bilgi çağı bilgi yönetimi ve bilgi sistemleri. Çizgi Yayınevi, Konya, Türkiye, pp: 1-11.

Özğan Ö. 2017. Vocational school computer technologies department evaluation of skills of using information technologies in terms of sector and student (Diyarbakır province example). MSc thesis, Fırat University, Institute of Science, Elazığ, Türkiye, pp: 96.

Palaz S, Boz İ. 2008. Üniversite mezunu yetişkinlerin farklı organizasyonlarda gönüllü hizmet vermesini etkileyen faktörler. Balıkesir Üni Sos Bil Ens Derg, 11(19): 95-106.

Selvi Ö. 2012. Bilgi toplumu, bilgi yönetimi ve halkla ilişkiler. Gümüşhane Üni İlet Fak E Derg, 1(3): 191-214.

Tonta Y. 2004. Bilgi yönetiminin kavramsal tanımı ve uygulama alanları. Kütüphaneciliğin Destanı Sempozyumu, Ekim 21-24, Hacettepe Üniversitesi, Ankara, Türkiye, pp: 55-68.

Tor E, Erden O. 2004. İlköğretim öğrencilerinin bilgi teknolojilerinden yararlanma düzeyleri üzerine bir araştırma. Türk Online Eğt Tek Derg, 3(1): 120-130.

Tunç A, Belli A, Aydoğdu Y. 2017. Dijitalleşen kamu hizmetleri açısından gıda tarım ve hayvancılık bakanlığı değerlendirilmesi. Süleyman Demirel Üni İİBF Derg, 22(15): 1921-1931.

UTGB. 2021. Ulusal Tarım Gıda Birliği. URL: http://www.utgb.org (accessed date: December 8, 2024).

Yamane T. 2001. Temel Örnekleme Yöntemleri. 1. Baskı (Çevirenler: Esin A, Aydın C, Bakır MA, Gürbüzsel E), Literatür Yayıncılık, İstanbul, Türkiye, pp: 509.

Black Sea Journal of Agriculture

doi: 10.47115/bsagriculture.1639335

Open Access J
e-ISSN: 2618 – 6578

Research Article
Volume 8 - Issue 2 : 263-269 / March 2025

DETERMINATION OF SOME SPRAYING CHARACTERISTICS OF DIFFERENT AIR INDUCTION NOZZLES

Ercan TURGUT[1] , Hüseyin DURAN[2*]

[1]*Agrotez Agriculture Industry and Trade Joint Stock Company, 34810, İstanbul, Türkiye*

[2]*Ondokuz Mayis University, Faculty of Agriculture, Department of Agricultural Machinery Engineering and Technology, 55200, Samsun, Türkiye*

Abstract: Although there are alternative methods of struggle against diseases, pests and weeds in agricultural production, chemical control method is widely preferred. The ability of the pesticide to show sufficient effect on the target surfaces depends on the correct functioning of the nozzles. In plant protection applications, it is necessary to make the pesticide in the appropriate nozzle type, spraying height, spraying pressure, forward speed and norm values. This study was carried out to determine the surface coverage, droplet frequency and volume median diameter of different air induction nozzles at different spraying heights and spray pressures. In the study; four different nozzles, three with air induction (ID 90-03 C, IDK 120-03, AITX B 8003) and one with hollow cone nozzle (TR 80-03), were used. This study conducted in field conditions. Two different spray heights (50 cm, 70 cm) and three different spray pressures (2 bar, 4 bar, 6 bar) were applied. As a result of the applications, the volume median diameter, droplet frequency and surface coverage were examined. Water sensitive papers and Image Tool for Windows V3 image processing program were used to determine the volume median diameter and surface coverage. The excel program was used to calculate the droplet frequency values. According to the results of the research, the highest surface coverage rate was achieved with 37.29% at IDK 120-03 nozzle at 70 cm spraying height and 6 bar spray pressure. The lowest surface coverage was obtained with the TR 80-03 nozzle at a spray height of 70 cm and pressure of 6 bar with 9.33%. The largest volume median diameter was 547.01 µm in AITX B 8003 nozzle and 256.60 µm in the smallest volume median diameter TR 80-03 nozzle. The highest droplet frequency is 74 (pcs / cm^2) at TR 80-03 nozzle with 50 cm spraying height and 2 bar spray pressure, while the lowest droplet frequency is 8 (pcs / cm^2) at 50 cm spray height and 2 bar spray pressure at AITX B 8003 nozzle was obtained.

Keywords: Air induction nozzle, Surface coverage, Volume median diameter, Water sensitive paper, Image processing

***Corresponding author:** Ondokuz Mayis University, Faculty of Agriculture, Department of Agricultural Machinery Engineering and Technology, 55200, Samsun, Türkiye
E mail: huseyin.duran@omu.edu.tr (H. DURAN)
Ercan TURGUT https://orcid.org/0000-0001-6259-1908
Hüseyin DURAN https://orcid.org/0000-0002-2740-8941

Received: February 14, 2025
Accepted: March 03, 2025
Published: March 15, 2025
Cite as: Turgut E, Duran H. 2025. Determination of some spraying characteristics of different air induction nozzles. BSJ Agri, 8(2): 263-269.

1. Introduction

In recent years, there has been an increasing demand in the agricultural industries for precision agriculture and affordable tools and equipment to meet the demands of the current world population. It is important for farmers to increase productivity in agriculture and reduce production costs in order to minimize yield losses in crop production. For these purposes, the importance of agricultural mechanization is increasing day by day.

Despite the physico-mechanical, genetic, biological and biotechnical methods of controlling diseases, pests and weeds in agricultural production, chemical control is the most widely used method in the world and in our country. Pesticides are used in chemical control. Pesticide use is growing in Turkish agriculture, though it varies year to year. Due to the negative effects of pesticides on human health, environment and natural balance and increasing production costs, they should be applied more sensitively, carefully and with minimum pesticide loss (Dursun, 2000).

Both the safety and effectiveness of pesticide use are largely determined by the technical condition of the equipment used for application (Anonymous, 2020). Over the years, pesticides are becoming more specific in terms of application techniques by users in terms of the variability of environmental factors and adaptation to new technologies. Therefore, a higher standard in application technique is demanded. In pesticide applications, it is aimed to ensure homogeneous transport of the active substance to the target, retention on the target surface, minimization of variation in drug distribution and drift level, and maximum biological efficacy at the recommended dose. The design features and operating parameters of the sprayers used for this purpose affect the success of agricultural control (Çomaklı, 2017). Even in cases where spraying tools and equipment are selected correctly, the expected success cannot be achieved if spraying is not carried out with the correct pulverization characteristics (average drop diameters, drop frequency, surface coverage value) that will provide sufficient surface coverage. In spraying, it is necessary to minimize the damage to the natural balance while providing the highest effect of the pesticide on the target surface. This can be achieved by correctly selecting the pulverization characteristics that ensure that the pesticide is delivered to the target surface and placed there.

Achieving the desired success in terms of agricultural pest control application technique depends on the correct selection of equipment, pesticide, target surface and time. Although nozzles are one of the cheapest parts of sprayers, they have a very important effect in providing biological efficacy in the control of diseases, pests and weeds. The pesticide application efficiency varies depending on the nozzle type, drop diameter and pesticide distribution pattern. Diversity in sprayer can be achieved by selecting different nozzle types (Çelen, 2013) or pressure settings (Pearson and Reed, 1993).

Since 30% of the pesticide consumed cannot be delivered to the target surfaces, it causes economic losses and environmental pollution. Due to pesticide loses, the required homogeneity in spraying cannot be achieved. Studies show that there is an average of 25-30% crop loss in areas where plant protection procedures are not applied. In pesticide applications, the drop diameter values formed by the nozzles are known as important characteristics. Drop diameter has a direct effect on pulverization characteristics such as collection of drops on target surfaces, surface coverage and drop frequency. Image Processing Method is widely used to determine drop diameter values and surface coverage rate (Moor et al., 2000; Duran, 2012).

Image processing technique is used in many areas such as determination of drop size, drop frequency and surface coverage in pesticide applications. V3 Image Tool (UTHSCSA ImageTool) is used to determine drop diameters and surface coverage depending on spray pressure and spray height, which are effective parameters on drop diameter and surface coverage rate. Image analysis functions include dimensional (distance, angle, perimeter, area) and grey scale measurements (point, line and area histogram with statistics). The software has a multi-document interface (MDI) application that supports any number of windows (images) simultaneously (Anonymous, 2024a).

Water sensitive papers are used in image processing techniques, especially in the determination of volume median diameter and surface coverage. Water-sensitive papers are preferred because they are used in natural application conditions and allow their analyses to be performed later. Water-sensitive paper, which is a hard paper with a specially coated yellow surface, is coloured dark blue by liquid drops hitting it. Firstly, the papers are placed in the target area before spraying the liquid and collected after drying after the application. The collected water-sensitive papers are used to calculate volume median diameter and coverage rates (Anonymous, 2024b).

Nozzles working with air flow are more commonly known as pneumatic nozzles. This type of nozzles are used in air flow sprayers. The energy required for the disintegration of the liquid and the transport of the drops in air-flow nozzles is provided by the air flow (Yağcıoğlu, 2016).

Prevention of drift in pesticide applications is becoming more important day by day. For this purpose, as a result of research on different nozzle types, air suction nozzle types have become more preferred in recent years due to the advantages they provide in terms of drift. In these nozzle types, the liquid is mixed with the air sucked into the nozzle before leaving the nozzle. In this way, the drop diameter size increases and its drift by the wind (Çelen, 1998) can be significantly reduced. It should be known that nozzle types and spray height are the most important parameters that prevent entrainment and research on this subject is needed (Balsari et al., 2017). At the same time, the ability to form conical or fan beam is seen as the most important advantage of air suction nozzle types besides reducing drift (Çilingir and Dursun, 2010).

This study was conducted to determine the volume median diameter, surface coverage and drop iftfrequency of some nozzle types at different spray heights and spray pressures.

2. Materials and Methods

The field trials of the study were carried out in the trial areas of Bornova Agricultural Pest Control Research Institute of the Ministry of Agriculture and Forestry in 2020. The analyses and evaluations of the water-sensitive papers obtained from the trials were carried out at Ondokuz Mayıs University, Faculty of Agriculture, Department of Agricultural Machinery and Technologies Engineering. In the study; four different nozzles, three with air induction (ID 90-03 C, IDK 120-03, AITX B 8003) (Dafsari et al., 2021) and one with hollow cone nozzle (TR 80-03) were used for comparison. Water sensitive papers (WSP) (Syngenta) with dimensions of 26x76 mm were used as the sampling surface to determine the number of droplets, volume median diameter, and the surface coverage (Salyani et al., 2013; Açık, 2018). A Scanner device was used for scanning the water-sensitive papers. Lechler brand oil bath manometer was used to measure the spray pressures. The experiments were carried out with a suspended type field sprayer (Agrotek, Manisa-Türkiye) connected to a Massey Ferguson 3.050 model tractor (Figure 1). In addition, air velocity was measured with a digital thermo-anemometer with probe type during the trials.

Figure 1. Sprayer used in the trials

2.1. Statistical Analysis

Three different air suction nozzle types (ID 90-03 C, IDK 120-03, AITX B 8003) and TR 80-03 hallow cone nozzle type were used for comparison (Caner, 2007). The experiments were carried out with 4 replications at two different spray heights (50 cm, 70 cm) and three different spray pressure (2 bar, 4 bar, 6 bar) (Turgut, 2021). The water-sensitive papers used as sampling surface in the applications were placed on wooden wedges (Figure 2). These wedges were placed 3 metres apart, one at each nozzle level (Figure 3).

Figure 2. Wedges for WSP.

Figure 3. Placement of WSP on the wedges in the trial area.

The stain diameters (Figure 4) formed by the painted drops on water-sensitive papers (Çelen and Aktaş, 2000; Özyurt et al., 2022) were determined by analysing them with an image processing software (Fox et al., 2003). In addition, Fox et al., (2001) stated in their study that although there are many methods for determining the surface coverage, the most easily applicable method is the analysis with water-sensitive papers. Water sensitive papers were scanned with a scanner at 600 dpi and transferred to computer (Figure 5) in JPEG format (Jeon et al., 2011). They were analysed in computer environment with UTHSCSA Image Tool for Windows V3 image processing software. Stain diameters analysed on water-sensitive papers (Duran et al., 2013) were calculated by using the spread factor coefficients and volume median diameter (μm) (VMD) were calculated in excel computer program (Duran, 2012). Surface coverage (%) and droplet number (pcs/cm^2) values of the drops deposited on the water-sensitive papers scanned and saved in Tiff format in the image processing software (Zhu et al., 2011) were calculated.

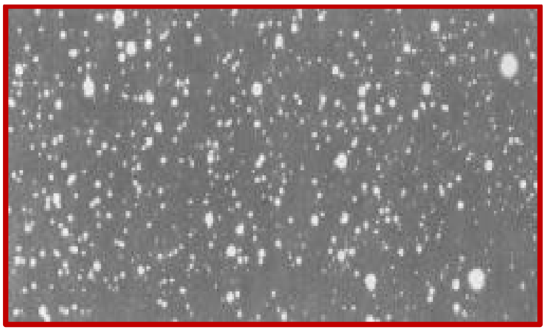

Figure 4. After the spraying WSP

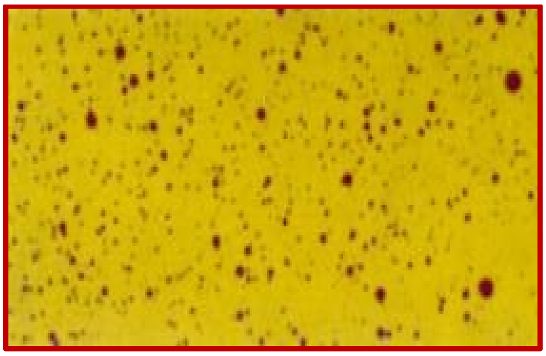

Figure 5. WSP on computer for analysis.

3. Results and Discussion

The nozzle types used in the experiments were applied at different spray heights and spray pressures at the constant forward speed and pesticide application rate. As a result of the applications, volume median diameter (VMD), droplet number (DS) and surface coverage (CR) values were reported (Güler et al., 2006).

3.1. Volume Median Diameter

The VMD values obtained as a result of the experiments are given in table 1. The largest VMD value of 547.01 μm was obtained with the AITX B 8003 nozzle. The smallest VMD value was obtained as 256.60 μm with TR 80-03 nozzle type.

Table 1. VMD values obtained in the trials

Nozzles		VMD (µm)
AITX B 8003	A	547.01
ID 90-03 C	B	461.68
IDK 120-03	B	446.89
TR 80-03	C	256.60

LSD= 27.89, CV = % 11.31, * The difference between values with different letters is significant (P < 0.05)

In general, for air suction nozzle types, larger VMD values were obtained at 50 cm spray height compared to 70 cm spray height applications (Table 2). Air induction nozzle types (ID 90-03 C and IDK 120-03) were classified as very coarse and AITX B 8003 nozzle type was classified as very coarse. In terms of VMD values obtained from air suction nozzle types, they were in the VMD class and in the group with the least risk of drift (ASABE, 2009). Hofman (1999) emphasised the importance of the correct selection of VMD for uniform spraying in his study to determine the drift and surface coverage relationships of drop diameters. In the hollow cone nozzle, the smallest VMD values were calculated as 277.57 µm for 50 cm and 235.63 µm for 70 cm at both spray heights compared to air suction nozzle types, respectively. Similarly, (Li et al., 2022) determined that the drop diameter decreased with increasing spray height, but not significantly.

Table 2. Spray height and VMD relationship

Nozzles	Spray height (cm)		VMD (µm)
AITX B 8003	50	A	568.15
AITX B 8003	70	B	525.86
ID 90-03 C	70	C	477.13
IDK 120-03	70	CD	457.09
ID 90-03 C	50	CD	446.23
IDK 120-03	50	D	436.70
TR 80-03	50	E	277.57
TR 80-03	70	F	235.63

LSD= 39.44, CV = % 11.31, * The difference between values with different letters is significant (P < 0.05)

3.2. Droplet Numbers

It was determined that the droplet frequency values obtained at different spray height and spray pressure applications were different depending on the nozzle types. When table 3 is analysed, the highest droplet frequency value of 74 (pcs/cm²) was obtained at 50 cm spray height and 2 bar spray pressure value in TR 80-03 nozzle type. In air suction nozzle types, the highest droplet frequency values were generally obtained at 50 cm spray height and 2 bar spray pressure value. In this group, the highest droplet frequency values were obtained only in AITX B 8003 nozzle type at 50 cm spray height and 6 bar spray pressure.

In the applications where the spray height was 50 cm, the highest droplet frequency in air induction nozzles was 31 pieces/cm² in ID 90-03 C nozzle type in 2 bar spray pressure application and 31 pieces/cm² in IDK 120-03 nozzle type in the same application conditions. In the applications, it was determined that the droplet frequency values tended to decrease with the increase in spray pressure value when the spray height was 50 in ID 90-03 C and IDK 120-03 air induction nozzles. In the case where the spray height value was 70 cm, it was determined that the droplet frequency decreased with the increase in the pressure value. This situation was completely reversed in AITX B 8003 nozzle type. In air induction nozzle, 31 pieces/cm² droplet frequency was obtained in ID 90-03 C nozzle type. The same spray height and spray pressure values were obtained for the IDK 120-03 air induction nozzle. In AITX B 8003 nozzle, the highest droplet frequency value was obtained with 14 pieces/cm² at 50 cm spray height and 6 bar spray pressure applications.

Table 3. Spray height, Spray pressure and drop frequency relationship

Nozzless	Spray height (cm)	Spray pressure (bar)		Drop frequency (adet/cm²)
TR 8003	50	2	A	74
TR 8003	50	4	B	60
TR 8003	70	2	B	60
TR 8003	50	6	C	43
TR 8003	70	6	CD	37
ID 90-03	50	2	DE	31
IDK 120-03	50	2	DF	31
IDK 120-03	70	6	EG	30
IDK 120-03	50	4	EG	27
IDK 120-03	50	6	EG	26
ID 90-03 C	50	6	EH	25
ID 90-03 C	50	4	EH	25
TR 8003	70	4	FH	24
ID 90-03 C	70	4	GI	23
IDK 120-03	70	4	HJ	18
IDK 120-03	70	2	HJ	18
ID 90-03 C	70	2	HJ	18
ID 90-03 C	70	6	IJ	17
AITX B 8003	50	6	JK	14
AITX B 8003	70	4	JK	14
AITX B 8003	50	4	JK	12
AITX B 8003	70	6	JK	12
AITX B 8003	70	2	K	9
AITX B 8003	50	2	K	8

LSD= 7.03, CV = % 18.01, * The difference between values with different letters is significant (P < 0.05)

3.3. Surface Coverage

As a result of the applications, it was determined that there were statistical differences between the surface coverage obtained according to the spray height and spray pressures in nozzle types. Similarly, spraying from the appropriate height affects the surface coverage as well as the uniformity of drop distribution. Lower spray height may cause uneven distribution uniformity (Dou et al., 2021). Wang et al. (1995) found that the effects of spray height on drop distribution uniformity were statistically significant.

In the applications where the spraying height was 50 cm and 70 cm in air induction nozzle types, the surface coverage were close to each other when the spray pressure were 6 bar. It was observed that surface coverage decreased with the decrease in spray pressure. Especially in 2 bar spray pressure applications, there was a decrease in the surface coverage in air induction nozzles (Table 4).

Table 4. Spray height, Spray pressure and surface coverage relationship

Nozzles	Spray height (cm)	Spray pressure (bar)		surface coverage (%)
IDK 120-03	70	6	A	37.29
IDK 120-03	50	4	AB	36.95
IDK 120-03	50	6	AC	36.19
ID 90-03 C	50	6	AD	35.64
ID 90-03 C	70	6	AE	35.39
AITX B 8003	50	6	AF	33.54
ID 90-03 C	50	4	AG	32.22
ID 90-03 C	70	4	AH	30.83
ID 90-03 C	50	2	BH	29.85
IDK 120-03	50	2	CH	29.47
AITX B 8003	70	4	DI	28.57
TR 8003	50	4	EI	28.16
TR 8003	50	2	EI	28.10
IDK 120-03	70	4	FI	26.66
AITX B 8003	50	4	GJ	25.92
AITX B 8003	70	6	GJ	25.67
IDK 120-03	70	2	HK	24.14
ID 90-03 C	70	2	IL	21.39
AIXT B 8003	50	2	IL	18.94
TR 8003	70	2	JL	18.87
AITX B 8003	70	2	KL	17.85
TR 8003	50	6	LM	15.81
TR 8003	70	4	M	9.74
TR 8003	70	6	M	9.33

LSD= 3.73, VK = % 19.87, * The difference between values with different letters is significant ($P < 0.05$)

Klotchkov et al. (1998) determined in their study that it is possible to reduce the losses in pesticide applications by 1.2-2.8% with the correct selection of spray height and spray pressure. In addition, Lardoux et al. (1998) investigated the effects of spray height, forward speed, nozzle type and nozzle position angles on surface coverage rate and found that these parameters were effective on surface coverage rate, evaporation and drift. (Pan et al., 2025) determined that drift increased with spray height in their study.

IDK 120-03 nozzle type, which is one of the air induction nozzle types, provided very close surface coverage at 4 and 6 bar spray pressure in 50 and 70 cm spray height applications. In this nozzle type, 36.95% surface coverage was obtained at 50 cm spray height and 4 bar spray pressure, while 36.19% surface coverage was obtained in 70 cm and 6 bar applications. The lowest surface coverage was obtained with 9.33 % at 70 cm spray height and 6 bar spray pressure at hollow cone nozzle (TR 8003). Chiu et al. (1999) reported that surface coverage could also be determined in their study in which they used water sensitive papers and image processing programme to determine pesticide losses. They also found that the surface coverage decreased when the spray height or forward speed was increased or the spray pressure was decreased.

In general, the highest surface coverage were obtained in applications where the spray height was 50 cm and the spray pressure was 6 bar for each nozzle type. In IDK 120-03 nozzle type, which is an air induction nozzle, 36.95 % at 4 bar spray pressure value at 50 cm spray height and higher surface coverage (36.19 %) was obtained compared to 6 bar (Table 4). There were cases where the spray pressure was low but the surface coverage was high. It can be said that these situations may be due to the fact that the trials were carried out under natural conditions during the trials and cannot be considered as a negative result since the values are close to each other. Açık (2018) conducted a study to determine the surface coverage and droplet distribution uniformity of some nozzle types at different spray heights and forward speed and determined that the surface coverage increased with the minimum level of spray height.

4. Conclusion

Although there are alternative control methods against harmful organisms (diseases, pests, weeds) in order to obtain the desired quality and quantity of products in agricultural production, chemical control method is widely preferred. In order to achieve the expected success in terms of agricultural pest control application technique, the pesticide, target surface and application time should be selected correctly together with the equipment to be used in the application. Nozzles used in sprayers have a significant effect on biological success when evaluated in terms of equipment.

In this study, volume median diameter (VMD), droplet frequency (DS) and surface coverage (SC) were analysed with four different nozzle types, three with air induction (ID 90-03 C, IDK 120-03, AITX B 8003) and one with hollow cone (TR 80-03), two different spray heights (50 and 70 cm) and three different spray pressure (2, 4, 6 bar).

The largest VMD was 547.01 µm for the AITX B 8003 nozzle with air induction. The smallest drop diameter was 256.60 µm in TR 80-03 nozzle with hollow cone nozzle. Considering the spray height, the largest VMD was 568.15 µm and 525.86 µm in AITX B 8003 nozzle at spray heights of 50 cm and 70 cm, respectively. In other air induction nozzles, 477.13 µm and 457.09 µm were obtained at 70 cm spray height in ID 90-03 C and IDK 120-03 nozzles, respectively. In TR 80-03 hollow cone, the highest VMD value was obtained with 277.63 µm at 50 cm spray height.

In both ID 90-03 C and IDK 120-03 nozzle types, the highest droplet frequency was 31 pieces/cm² in applications where the spray height was 50 cm and the spray pressure was 2 bar. In AITX B 8003 nozzle, the highest droplet frequency of 14 pieces/cm² was obtained in 50 cm spray height and 6 bar spray pressure applications. In TR 80-03 nozzle type, 31 pieces/cm² was obtained with a spray height of 50 cm and a spray pressure of 2 bar.

IDK 120-03 nozzle type provided the highest surface coverage rate with 37.29 % at 70 cm spray height and 6 bar spray pressure. For this nozzle type, 50 cm spray height and 4 bar spray pressure which provided 36.95% coverage rate, can be preferred. Air suction ID 90-03 C nozzle type provided the highest value with 35.64 % surface coverage at 50 cm spray height and 6 bar spray pressure applications. It can be said that this nozzle type can be preferred for 50 cm spray height and 4 bar spray pressure applications since it provided 32.22% surface coverage. AIXT B 8003 nozzle provided the highest surface coverage of 33.54 % in 50 cm spray height and 6 bar spray pressure applications.

The hollow cone nozzle (TR 80-03) used in the trials provided the highest surface coverage with 28.16 % at 50 cm spray height and 4 bar spray pressure.

During the trials, the tractor forward speed was selected as 3.85 km/h (=1.07 m/sec) and the average air temperature was 33 ^{0}C, relative humidity was 68% and wind speed was 3.24 km/h (=0.9 m/sec).

As a result, the most suitable values in terms of surface coverage, VMD and droplet frequency were obtained at different spray height and spray pressure applications. Considering the pesticide application quality and drift risk of air induction nozzle types in terms of VMD, surface coverage and droplet frequency, it is seen that the spray height is 50 cm and the spray pressure is 4 bar. In the hollow cone, it is concluded that when the spray height is 50 cm and the spray pressure is 4 bar, the appropriate value is reached in terms of surface coverage, VMD and droplet frequency.

Author Contributions

The percentages of the authors' contributions are presented below. All authors reviewed and approved the final version of the manuscript.

	H.D.	E.T.
C	70	30
D	80	20
S	90	10
DCP	60	40
DAI	70	30
L	50	50
W	70	30
CR	80	20
SR	80	20
PM	80	20
FA	60	40

C= concept, D= design, S= supervision, DCP= data collection and/or processing, DAI= data analysis and/or interpretation, L= literature search, W= writing, CR= critical review, SR= submission and revision, PM= project management, FA= funding acquisition.

Conflict of Interest

The authors declared that there is no conflict of interest.

Ethical Consideration

Ethics committee approval was not required for this study because there was no study on animals or humans.

Acknowledgments

This article was prepared from the master's thesis study carried out in the Department of Agricultural Machinery and Technologies Engineering at Ondokuz Mayıs University.

References

Açık N. 2018. Püskürtme memelerinin düşük dacimde yüzey kaplama ve damla dağılım düzgünlüğü açısından karşılaştırılması. Yüksek Lisans Tezi, Erciyes Üniversitesi, Fen Bilimleri Enstitüsü, Kayseri, Türkiye, ss: 71.

Anonymous. 2020. Food and agriculture organization of the united nations (FAO). http://www.fao.org/site (accessed date: December 29, 2020).

Anonymous. 2024a. https://imagetool.software.informer.com/ (accessed date: December 10, 2024).

Anonymous. 2024b. https://www.syngenta.com.au/awri. (accessed date: December 1, 2024).

ASABE. 2009. ASABE Standard 572.1: Spray nozzle classification by droplet spectra. American Society of Agricultural and Biological Engineers, St. Joseph, MI, Miami, USA.

Balsari P, Gil E, Marucco P, van de Zande J C, Nuyttens D, Herbst A, Gallart M. 2017. Field-crop-sprayer potential drift measured using test bench: Effects of boom height and nozzle type. Biosystem Engin, 154: 3-13.

Caner Ö. 2007. Yardımcı hava akımlı hidrolik pülverizatörle bağ ilaçlamasında toprak yüzeyine sürüklenmeyi azaltmaya yönelik en uygun kullanım koşullarının belirlenmesi. Doktora Tezi, Ege Üniversitesi, Fen Bilimleri Enstitüsü, İzmir, Türkiye, ss: 216

Çelen İ. H. 1998. Yelpaze hüzmeli püskürtme memelerinde aşınmanın pülverizasyon karakteristiklerine etkisi üzerine bir arastırma. Doktora Tezi, Tekirdağ Üniversitesi, Fen Bilimleri Enstitüsü, Edirne, Türkiye, ss: 105 s.

Çelen I. H. Aktas T. 2000. The effect of drop size on drift. EurAgEng 2000, Paper No: 00-PM-052, Warwick, U.K.

Çelen İ. H. 2013. Tarımsal mücadelede püskürtme memeleri. Toprak Ofset, Tekirdağ, Türkiye, ss: 111.

Chiu H W, Lee F F, Liang L S. 1999. Using image processing technique to measure spray coverage. J Agri Res China, 48(4): 96-110.

Çilingir İ, Dursun E. 2010. Bitki koruma makinaları. Ankara Üniversitesi Ziraat Fakültesi Yayınları. Yayın No:1531, Ankara, Türkiye, ss: 56.

Çomaklı, M. 2017. Poliasetal (pom) meme plakalarında püskürtme açısına etki eden faktörler ve pülverizasyon karakteristikleri. Yüksek Lisans Tezi, Atatürk Üniversitesi, Fen Bilimleri Enstitüsü, Tarım Makineleri Anabilim Dalı, Erzurum, Türkiye, ss: 78.

Dafsari R. A, Yu S, Choi Y, Lee J. 2021. Effect of geometrical parameters of air-induction nozzles on droplet characteristics and behaviour. Biosystems Engin, 209: 14-29.

Dou H, Wang S, Zhai C, Chen L, Wang X, Zhao X. 2021. A lidar sensor-based spray boom height detection method and the corresponding experimental validation. Sensors, 21(6): 2107.

Duran H. 2012. Fındık kurdu [*Curculio nucum* (L.)]'nda ilaç uygulama etkinliğinin iyileştirilmesi. Doktora Tezi, Ankara Üniversitesi, Fen Bilimleri Enstitüsü, Tarım Makinaları Anabilim Dalı, Ankara, Türkiye, ss: 130.

Duran H, Çilingir İ, Yurtlu Y B. 2013. Pülverizasyonda lazer ve leke yönteminde damla çap değerlerinin karşılaştırılması. 1. Bitki Koruma Ürünleri ve Makineleri Kongresi. 2-5 Nisan, Antalya, Türkiye, ss: 63.

Dursun E. 2000. Meme aşınmasının pülverizasyon karakteristiklerine etkileri. Ekin Yayıncılık, Ankara, Türkiye, ss: 43.

Fox R. D, Derksen R. C, Krause C. R, Cooper J.A, Ozkan H. E. 2001. Visual and image system measurement of spray deposits using water sensitive paper. http://www.nal.usda.gov/ttic/tektran/data/000012/62/0000126219.html. (accessed date: November 10, 2001).

Fox R D, Derksen R C, Cooper J A, Krause C R, Ozkan H E. 2003. Visual and image system measurement of spray deposits using water-sensitive paper. Applied Engin Agri, 19(5): 549-552.

Guler H, Zhu H, Ozkan H. E, Derksen R. C, Yu Y, Krause C. R. 2006. Spray characteristics and wind tunnel evaluation of drift reduction potential with air induction and conventional flat fan nozzle. 2006 ASAE Annual Meeting, American Society of Agricultural and Biological Engineers, 9-12 July 2006, Portland, Oregon, USA, pp: 27.

Hofman V. 1999. Spray droplet size relates to coverage and drift. http://www.ext.nodak.edu/extnews/newsrelease/1999/052799/08agspra.html. accessed date: August 22, 2020).

Jeon H Y, Zhu H, Derksen R C, Ozkan H E, Krause C R, Fox R D. 2011. Performance evaluation of a newly developed variable-rate sprayer for nursery liner applications. American Soc Agri Biol Engin, 54(6): 1997-2007.

Klotchkov A, Markevich, A, Straksiene J. 998. Field tecnologies and enviroment. Proceeding of the International Conference, 24-25 September, Raudondvaris, Lithuania, pp: 81-85.

Lardoux Y, Sinfort C, Bonicelli B, Enfalt P. 1998. Graund spray coverage study under a field sprayer boom. Brighton Crop Protection Conference: Pest&Diseases 1998: Volume 1: Proceedings of an International Conference, 16-19 November, Brighton UK, pp: 315-316.

Li X, Chen L, Tang Q, Li L, Cheng W, Hu P, Zhang R. 2022. Characteristics on the spatial distribution of droplet size and velocity with difference adjuvant in nozzle spraying. Agronomy, 12(8): 1960.

Moor A de, Langenakens L, Vereecke E, Jacken P, Lootens P. 2000. Image analysis of water sensitive paper as a tool for the evaluation of spray distribution of orchard sprayers. Pesticide Application University of Surrey, Aspects of Applied Biology, No. 57, Guilford, UK, pp: 329-341.

Özyurt H B, Duran H, Çelen İ H. 2022. Determination of the application parameters of spraying drones for crop production in hazelnut orchards. J Tekirdag Agri Fac, 19(4): 819-828.

Pan X, Yang S, Gao Y, Wang Z, Zhai C, Qiu W. 2025. Evaluation of spray drift from an electric boom sprayer: Impact of Boom Height and Nozzle Type. Agronomy, 15(1): 160.

Pearson S, Reed T. 1993. Spray nozzle selection. World Agriculture, Hong Kong, China, pp: 49-50.

Salyani M, Heping Z, Roy D S, Naresh P. 2013. Assessment of spray distribution with water-sensitive paper. Agric Eng Int, 15(2): 101-111.

Turgut E. 2021. Farklı hava emişli meme tiplerinin bazı pülverizasyon karakteristiklerinin belirlenmesi. Yüksek Lisans Tezi Ondokuz Mayıs Üniversitesi, Fen Bilimleri Enstitüsü, Tarım Makinaları ve Teknolojileri Mühendisliği Ana Bilim Dalı, Samsun, Türkiye, ss: 62.

Wang L, Zhang N, Slocombe J W, Thierstein G E, Kuhlman D K. 1995. Experimental analysis of spray distribution pattern uniformity for agricultural nozzles. Applied Engineering in Agriculture, 11(1): 51-55.

Yağcıoğlu A. 2016. Bitki koruma makineleri. Ege Üniversitesi Yayınları, İzmir, Türkiye, ss: 295.

Zhu H, Salyani M, Fox R D. 2011. A portable scanning system for evaluation of spray deposit distribution. Comput Elect Agri, 76(1): 38-43.

Black Sea Journal of Agriculture
doi: 10.47115/bsagriculture.1630840

Open Access Journal
e-ISSN: 2618 – 6578

Research Article
Volume 8 - Issue 2: 270-285 / March 2025

GLOBAL COMPETITION IN WHEAT AND MESLIN, MAIZE AND RICE PRODUCTS: TÜRKİYE'S COMPETITIVENESS

Zeynep AKTAŞ ÇİMEN[1]*,

[1]*Akdeniz University, Social Sciences Vocational School, Department of Marketing and Advertising, Marketing Pr., 07030, Antalya, Türkiye*

Abstract: Global trade in agricultural products is critical for food security. As the volume of trade has increased and become more complex, it has become important to assess global competition in the trade of agricultural products. The objective of the study is to assess Türkiye's position and level of specialization in relation to the competitiveness of the top 20 countries in the global export market for three key agricultural products wheat and meslin, maize and rice over the period 2004-2023. These three products were chosen due to their significant role in the global economy. For the analysis, data were selected using the Harmonized System (HS) 4-digit product codes from Trade Map database. Specifically, wheat and meslin are coded as "1001", maize as "1005", and rice as "1006". 20 years of data on the exports and imports of countries were used and analyzed with the Indices of Revealed Comparative Advantage, Net Exports and Export-Import Ratio. According to the results of the RCA analysis, Ukraine has the highest competitive advantage in the global wheat and meslin export market, while Türkiye is the most competitively disadvantaged country. In the maize export market, Argentina holds the highest competitive advantage, whereas Türkiye is the most disadvantaged. In the rice export market, Guyana has the highest competitive advantage, with Türkiye being the most disadvantaged country after Austria.

Keywords: Exports, Revealed comparative advantage, Competitiveness, Türkiye

***Corresponding author:** Akdeniz University, Social Sciences Vocational School, Department of Marketing and Advertising, Marketing Pr., 07030, Antalya, Türkiye
E mail: zaktas@akdeniz.edu.tr (Z. AKTAŞ ÇİMEN)
Zeynep AKTAŞ ÇİMEN https://orcid.org/ 0000-0003-0959-5314

Received: January 31, 2025
Accepted: March 07, 2025
Published: March 15, 2025

Cite as: Aktaş Çimen Z. 2025. Global competition in wheat and meslin, maize and rice products: Türkiye's competitiveness. BSJ Agri, 8(2): 270-285.

1. Introduction

Agriculture has been the foundation of both nutrition and economic activities throughout human history, and agricultural products being the first products traded by societies. Although the mechanization of production processes during the industrial revolution somewhat overshadowed the importance of agriculture, it remains a critical sector for national economies (Aysu, 2018). Cereals, which are especially rich in carbohydrates and provide energy to the body, continue to be a basic food source for both human nutrition and animal husbandry (Can, 2023).

Cereals, which provide almost half of the nutrient and calorie needs in humans diets, include about a dozen varieties as food. Among of humans in their diets, are about a dozen as food. Of these, wheat, maize and rice are the most important food sources for human beings and will continue to be staple foodstuffs with the projected increase in the global population (Ranum et al., 2014; Erbaş Köse and Mut, 2018; Fukagawa and Ziska, 2019; Umair Riaz et al., 2020; Gutiérrez-Moya et al., 2021; Bin Rahman and Zhang, 2023). However, as an important and strategic sector in the global economy, agriculture is highly sensitive to weather and climate conditions. Indeed, the Paris Agreement (December 2015), which includes a global response to climate change, clearly recognizes that climate change will have negative impacts on countries' agricultural production (FAO, 2016). Agricultural products have a privileged role in meeting the food needs of societies, supplying raw materials to the industrial sector, creating employment and contributing to exports. However, in today's world, the global climate crisis, increasing world population, conflicts and wars between countries affect the production, trade and competition of agricultural products, which have an important place in human nutrition. The competitiveness of countries in agricultural products can vary at national, regional and global levels, and there are also differences in performance across countries (Jambor and Babu, 2017). Trade in agriculture and food has expanded since the 2000s with the liberalization of regional and multilateral trade (FAO, 2022). Wheat, rice and maize are the main agricultural commodities that have played a role in this expansion and are the cornerstones of food production and trade worldwide (Ji et al., 2024). During the period from 2004 to 2023, global exports of the three major cereal crops increased approximately fourfold, whereas Türkiye's exports surged nearly one hundredfold. Russia (19.15%), Australia (15.16%), and Canada (14.38%) collectively hold a 48.69% share in the global export rankings of wheat and meslin, with Türkiye contributing

1.18%. In the global maize (corn) export market, the United States (25.60%), Brazil (25.47%), and Argentina (10.62%) together account for 61.69%, while Türkiye's share stands at 1.49%. Regarding global rice exports, India (29.99%), Thailand (14.66%), and Vietnam (12.54%) dominate with a combined share of 57.19%, whereas Türkiye's share is 0.51% (Trade Map, 2023). The competitiveness of agricultural products has therefore become an increasingly important issue in the global economy (Rodríguez et al., 2024) and one of the most important issues of the 21st century (Jambor and Babu, 2017). Understanding and improving agricultural competitiveness is therefore of paramount importance and is essential for a nation, sector or firm to be able to produce and export efficiently, sustainably and profitably in the face of evolving market demands (Thomé et al., 2023). Analyzing the competitiveness of agricultural products is crucial to provide policy recommendations and lessons on how to improve the competitiveness of agricultural products and food security in the long run (Jambor and Babu, 2017). Analysing trade dynamics such as competitiveness, export and import trends and global market access is crucial for understanding Türkiye's position in the global market for wheat and meslin, maize (corn) and rice. Recent studies have provided valuable insights into Türkiye's competitiveness in these products. These studies have analyzed the competitive situation of agricultural products in the global market from various dimensions (Şahin, 2016; Sarıçoban and Kösekahyaoğlu, 2016; Geetha and Srivastava, 2018; Govindasamy et al., 2023; Oktan, 2024).

This research paper sheds light on key aspects of trade dynamics and competitiveness of three agricultural commodities: wheat, rice and maize. The study aims to reveal the competitiveness of the top 20 leading countries in the global export market of wheat and meslin, maize (corn) and rice using data from the Trade Map (2023) database for the period 2004-2023. The top 20 export leaders of these three products were selected because they account for 95.53% of wheat and meslin exports, 95.62% of maize (corn) exports, and 95.28% of rice exports. Türkiye ranks 10th in maize (corn) exports, 17th in wheat and meslin exports, and 19th in rice exports among the 20 countries in the export ranking of these three products. This study will analyze. Türkiye's competitive position vis-à-vis the top twenty global exporters of these three agricultural products. Such research is crucial for adapting to the rapidly changing dynamics of the global economic environment and for focusing on a strategic restructuring of national agricultural and food systems.

The study consists of six chapters. Following the introductory section, which highlights the importance of the study, the second chapter examines the top 20 exporters of wheat, maize (corn), and rice in the global economy, as well as Türkiye's position in the global market. The third chapter reviews the current literature on the topic, while the fourth chapter outlines the study's methodology. The fifth chapter presents the research findings, and the sixth chapter concludes the study with a general evaluation of the researched topic.

1.1. Outlook for International Trade in Wheat and Meslin, Maize (Corn) and Rice

International trade plays a critical role in the growth of national economies and increases countries' access to foreign markets. In addition, international trade, creates new opportunities for local producers and provides product diversification, which plays an important role in stabilizing domestic markets and ensuring efficient use of resources (Sovcovici et al. 2024). According to Trade Map (2023), world exports of cereal crops consisting of wheat and meslin, maize (corn) and rice have increased approximately fourfold in the last 20 years, reaching 149881306 US Dollar thousand in 2023 (Figure 1).

Türkiye's exports of cereal crops, consisting of wheat and meslin, maize (corn) and rice, have increased nearly 100 times, reaching a staggering figure of 1697349 US Dollar thousand in 2023 (Figure 2). This rapid expansion is attributed to improvements in production and trade operations, which support the growth of the national agro-industrial sector and exports of agricultural and food products. In this context, assessing the competitiveness of agricultural exports is critical for improving the efficiency of production processes and developing effective marketing strategies.

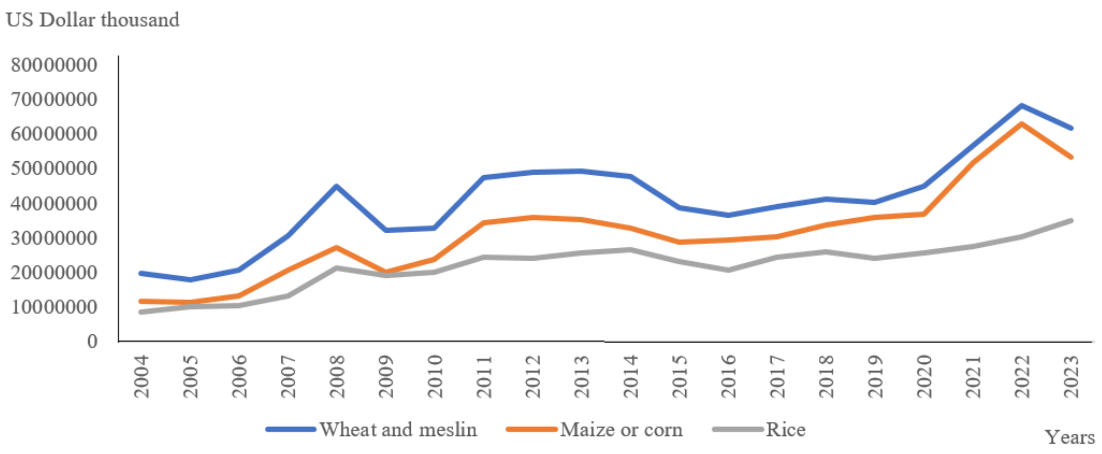

Figure 1. World wheat and meslin, maize (corn) and rice exports (2004-2023) (Trade Map, 2023).

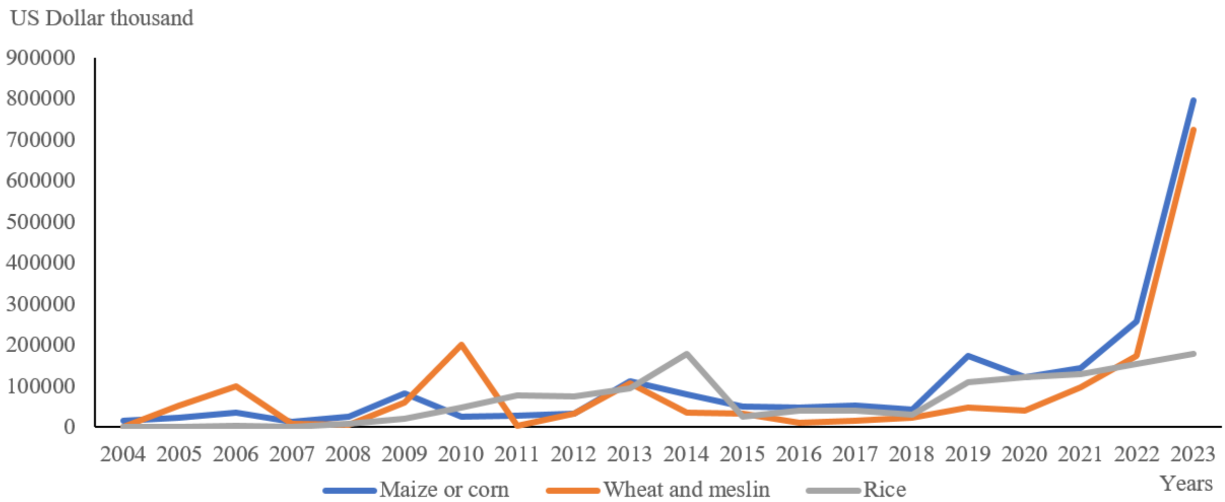

Figure 2. Türkiye's wheat and meslin, maize (corn) and rice exports (2004-2023) (Trade Map, 2023).

Table 1. Shares of top 20 countries in world total maize (corn), wheat and meslin, rice exports (2023) (Trade Map, 2023)

	Maize (Corn)		Wheat and Meslin		Rice	
Ranking	Country	%	Country	%	Country	%
1	USA*	25.60	Russia	19.15	India	29.99
2	Brazil	25.47	Australia	15.16	Thailand	14.66
3	Argentina	10.62	Canada	14.38	Viet Nam	12.54
4	Ukraine	9.29	USA	9.97	Pakistan	8.26
5	France	3.77	France	6.47	USA	5.78
6	Romania	3.14	Ukraine	4.78	Cambodia	5.39
7	Poland	2.42	Romania	3.62	China	2.82
8	South Africa	2.26	Poland	3.19	Italy	2.78
9	Russia	2.25	Germany	3.15	Myanmar	2.13
10	Türkiye	1.49	Kazakhstan	3.01	Brazil	1.78
11	Canada	1.43	Bulgaria	2.73	Uruguay	1.71
12	Paraguay	1.40	Lithuania	1.69	Belgium	1.34
13	Hungary	1.32	Argentina	1.42	Paraguay	1.19
14	India	1.32	Hungary	1.34	Netherlands	1.19
15	Myanmar	0.85	CR**	1.21	Australia	0.81
16	Bulgaria	0.71	Brazil	1.18	Djibouti	0.74
17	Pakistan	0.65	Türkiye	1.18	Guyana	0.69
18	Austria	0.65	Latvia	1.01	Spain	0.63
19	Serbia	0.52	Slovakia	0.75	Türkiye	0.51
20	Croatia	0.47	UK	0.56	Tanzania.	0.36
	Total	95.62	Total	95.93	Total	95.28

* United States of America ** Czech Republic *** United Kingdom.

Although the production of wheat, maize and rice, which are the most important food sources, shows regional differences, the USA ranks first with 25.60% share in maize (corn) exports, Russia with 19.15% share in wheat and meslin exports, and India with 29.99% share in rice exports (Table 1). The world export value of wheat is 61,543,142 thousand US Dollars (2023), with Türkiye accounting for 1.18% of world exports, amounting to 723,601 thousand US Dollars. For maize, world exports are valued at 53,447,386 thousand US Dollars (2023), with Türkiye accounting for 1.49% of world exports amounting to 795,323 thousand US Dollars. In rice, world exports are valued at 34,890,778 thousand US Dollars (2023), with and Türkiye accounting for 0.50% of world exports, amounting to 178,425 thousand US Dollars (Trade Map, 2023).

1.2. Literature Review

A better understanding of how competitive advantage relates to the real world is useful for determining the consequences of policy changes and clarifying economic welfare (Vollrath, 1991). Differences in relative agricultural productivity across countries reinforce the role of comparative advantage and, together with incentives to trade, increase the potential gains from trade (FAO, 2022). There are numerous studies in the literature on the measurement of OCA.

Şahin (2016) analyzed Türkiye's competitiveness in agri-food products with RCA, Explained Symmetric Comparative Advantage and Balance of Trade indices; Sarıçoban and Kösekahyaoğlu (2016), examined Türkiye's export competitiveness in agricultural product groups with RTA index; Geetha and Srivastava (2018) assessed India's corn export performance with RCA Index and Regression analysis; Pascucci (2018) utilized RCA, NEI, export market share and net export share indices to evaluate the competitive position of Italian roasting firms and the export competitiveness of the sector; Kutkowska and Szuk (2020) employed the Relative Trade Advantage (RTA), Export Market Share, Export Orientation, Relative Export Orientation, Hypothetical Exports and Trade Coverage indices to analyze trends in production, exports and imports, as well as the competitiveness of exporters in the global grain market; Nithyashree et al. (2020) investigated India's maize export performance with the RCA index; Maqbool et al. (2020) examined RCA, Vollrath index, Revealed Symmetric Comparative Advantage index (RSCA), Revealed Import Advantage (RMA) index, Revealed Trade Advantage (RTA) index and Net Export Index (NEI) for Pakistan's cereals trade competitiveness; Thomé and Paiva (2020) analyzed the international market structure and competitiveness of sparkling wine with RCA, NEI, Relative Position in the Market (RPM) and Hirschman-Herfindahl Index (HHI); Bashimov (2022) assessed Kazakhstan's comparative advantage in cereals exports using the RCA and RSCA indices; Thomé et al. (2023) evaluated the international market structure and export competitiveness of wine using the Revealed Symmetric Comparative Advantage (RSCA) Herfindahl-Hirschman Index and NEI; Govindasamy et al. (2023) analyzed the competitiveness of Pakistan's agricultural products (wheat, rice, maize, sugarcane and cotton) with using the RCA, Relative Export Advantage Index (RXA), RMA and Relative Import Advantage (RTA) indices; Oktan (2024) analyzed the competitiveness of Türkiye's cereals in comparison with G7 countries with RCA, RXA, RMA Revealed Competitiveness Index (RC), RTA, Export Specialization (ES), Net Trade (NT), Export Similiraty (ES) indices.

Although there are studies on the competitiveness of agricultural products in the literature, there are no studies specifically addressing the global competitiveness of Türkiye's maize (corn), wheat and meslin and rice products. However, people worldwide obtain 51% of their calories from just these three crops: rice, wheat and corn (Sing, 2022). Developed countries, on the other hand, never give up agriculture. They are leaders, especially in the production of critical products. It is urgent for Türkiye to develop strategies in this regard. This study aims to contribute to closing the gap in the relevant literature.

2. Materials and Methods

2.1. Data Collection

This paper uses country trade data to calculate and assess the competitiveness of Türkiye's agricultural products for wheat, maize, and rice over the period 2004-2023. Although data sources such as UN COMTRADE, OECD Database, Trade Map (United Nations Commodity Trade Statistics Database) play an important role in providing worldwide trade data, export data, especially at the product level, are often reported two or three years late. Therefore, the final year for the analysis is 2023. The analysis focuses on the top 20 global exporters of wheat, maize and rice for the period 2004-2023. The survey data used in the study were obtained by selecting the "Total-All products" classification from the Trade Map (2023) database. Since some of the countries identified for the analysis had missing data for the period 2004-2023, index values could not be obtained for those years. Only one country's data for a single year was corrected to avoid affecting the analysis value.

There are a total of 238 member countries registered as product exporters in the Trade Map (2023) database. The study covers 20 years from 2004 to 2023. Ten years of trade data is considered sufficient to examine the trade competitiveness of a product (Jagadeesh et al., 2024). The top twenty countries exporting maize (corn), wheat and meslin and rice products in the Trade Map (2023) database were analyzed to obtain index values. The share of the top 20 maize (corn) exporters in world maize (corn) exports is 95.62%; the share of the top 20 wheat and meslin exporters in world wheat and meslin exports is 95.93%; and the share of the top 20 rice exporters in world rice exports is 95.28%. The countries with incomplete data on trade in these three cereal crops are Russia (missing data for 2022-2023), Myanmar (missing data for 2004-2009), Serbia (missing data for 2004-2005), Djibouti (only data for 2009-2021-2022-2023), Guayana, which has incomplete data for maize (corn) and wheat and meslin, but provides complete data for rice for the period 2004-2023. In this study, HS product codes are used to assess the competitiveness of Türkiye's wheat, maize and rice exports vis-à-vis the top 20 countries in the global market. Products and codes according to the Harmonized System (HS) in the Trade Map database;

"1001" coded wheat and meslin,

"1005" coded maize (corn) coded and

"1006" coded is rice. The use of HS product codes to analyze the export competitiveness of a product is a common practice, as shown in other studies examining various commodity exporting countries (Hasan and Das, 2024). HS is a product nomenclature system currently used by more than 200 countries (Trade Map, 2023) and is a versatile tool covering more than 98% of internationally traded goods (Cornejo et al., 2023).

2.2. Methods Measures

Foreign trade is a stochastic process that changes over time under the influence of economic, political and environmental factors. Therefore, analyzing comparative advantages in foreign trade is important for developing specific strategies to improve foreign trade (Sovcovici et al., 2024). A country's competitive advantage, defined as its ability to produce in certain sectors (products) more efficiently, with higher quality, or more cost-effectively than other countries, is important for each country to analyze its comparative advantages and develop specific strategies to improve foreign trade (Balassa, 1965).

2.2.1. Balassa's revealed comparative advantage (RCA) index

The RCA index, based on the assumptions of the Ricardian trade model and also referred to as the Balassa (1965) index, is a quantitative method of analyzing the comparative advantage of exports. RCA is used to measure and evaluate a country's specialization in certain goods or services compared to other nations or regions (Balassa, 1965). The index value provides a general indication and overview of a country's export competitiveness and helps set foreign trade policy priorities. However, the RCA index does not take into account national practices that affect competitiveness such as tariffs, non-tariff measures, subsidies, etc. (United Nations Conference on Trade and Development, 2025). While the RCA index is widely used in the international trade literature, it is recommended to use it in combination with other indices to assess the sectoral effects of changes in trade barriers or to identify close competitors (French, 2017). The RCA index is calculated as the ratio of a country's exports in a sector to the share of world exports in that sector. If the index value indicates that a country's share of exports of a product exceeds its global share, the country is considered to have a declared comparative advantage in that product (Hasan and Das, 2024). Such analyses play an important role in shaping trade policies and accurately assessing international competition (Reed, 2024). The index was formulated by Balassa (1965) as equation 1:

$$RCA = \frac{X_{kt}^{j} \ / \ X_{t}^{j}}{X_{kt}^{w} \ / \ x_{t}^{w}} \tag{1}$$

In this context,

X^j_{kt} = j country's exports of product (sector) k in period t,

X^j_t = country j's total exports in period t.

X^w_{kt} = k product (sector) refers to total world exports in period t,

X^w_t = is the total value of world exports in period t (Sarıçoban et al., 2017).

If the RCA value is above “1”, it indicates that the country has a significant comparative advantage (specialization) in the product in question. If the RCA value is less than 1, it indicates that the country does not have a significant comparative advantage (no specialization) in the product in question (Granabetter, 2016; Geetha and Srivastava, 2018; Hasan and Das, 2024). The larger the RCA value, the more important the comparative advantage becomes (Hasan and Das, 2024). In order to facilitate the interpretation of the RCA Index results, Hinloopen and Van Marrewijk (2001) have made the following quadruple classification:

Class 1: $0 < RCA \leq 1$ Disadvantage (no competitiveness)

Class 2: $1 < RCA \leq 2$ Weak competitiveness

Class 3: $2 < RCA \leq 4$ Medium competitiveness

Class 4: $4 < RCA$ Strong competitiveness

Here, Class 1 indicates a state of disadvantage, i.e. the country has no comparative advantage in the sector in question, while Class 2, Class 3 and Class 4 indicate situations where the country's comparative advantage in the relevant sector has shifted from weak to strong competitiveness.

2.2.2. Net export index (NEI)

NEI is another key index used of the main indices used to analyze export competitiveness at the level of a specific product group (sector). It is a variation of the RCA index developed by Balassa (1965) and includes both exports and imports in the model (Marković et al., 2019). The NEI serves as an indicator of a country's external competitiveness by incorporating international export and import flows related to a specific product group (sector) (Marković, 2019). The index shows whether a country is a net exporter or net importer of a particular product group (sector). If a country is a net exporter of a particular product group, it indicates that the country has a competitive advantage in the global market in that product group (sector). Conversely, a high NEI value may indicate that the product is in demand in the world market and that the production capacity or productivity of that country is high (Banterle and Carraresi, 2007; Pascucci, 2018; Thomé and Paiva, 2020). NEI is formulated as in equation 2 (Sarıçoban and Kösekahyaoğlu, 2017):

$$NEI = \frac{X_{kt}^{j} - M_{kt}^{j}}{X_{kt}^{j} + M_{kt}^{j}} \tag{2}$$

In this context;

X^j_{kt} = denotes the exports of country j of product (sector) k in period t,

M^j_{kt} = shows the imports of product (sector) k of country j in period t (Aktaş Çimen and Sarıçoban, 2024). The NEI value ranges from “-1” to “+1” (Balassa and Noland, 1989). “+1” indicates pure exports and the highest comparative advantage; ‘-1’ indicates pure imports and the highest disadvantage; ‘0’ indicates balanced trade or maximum intra-industry trade (Amighini, 2004). When the index value is between “-1” and “0”, it indicates disadvantage; when it is between “0” and “+1”, it indicates advantage; and when it is equal to “0”, it indicates that exports and imports of a given product are balanced. In other words, NEI measures the degree of specialization of a country's exports of a particular good (Asciuto et al., 2008; Saboniene, 2009).

2.2.3. Export-import ratio index (EIRI)

The EIRI is related to the concept of RCA and indicates the competitiveness of a country in a particular product group, specifically the level of specialization in the global trade of that product group (Saboniene, 2009; Bashimov, 2018). The index shows the ratio of a country's export share to its import share in any product and the EIRI is formulated as in equation 3 (Balassa, 1977; Sarıçoban and Kösekahyaoğlu, 2017):

$$EIRI = \frac{X^j_{kt} \ / \ X^j_t}{M^j_{kt} \ / \ M^j_t} \qquad (3)$$

In this context;

X^j_{kt} = 'j' country's exports of product group 'k' in period 't',

X^j_t = total exports of country 'j' in period 't',

M^j_{kt} = 'j' country's imports of 'k' product group in period 't',

M^j_t = Total imports of country 'j' in period 't'. An EIRI value greater than 1 indicates that the country specializes in the relevant product and has a competitive advantage, while a value less than 1 indicates that the country does not specialize and is competitively disadvantaged (Mikic, 2005).

3. Results and Discussion

In the analyses with RCA, NEI and EIRI for the top 20 countries including Türkiye in the global export market of wheat and meslin, maize (corn) and rice, the coefficients of revealed comparative advantage are calculated based on Trimmed Mean (TM: It refers to the removal of the highest and lowest values from a series and taking the arithmetic mean of the remaining values (Statistics How To, 2025) values. In addition, some abbreviations used in the tables are as follows:

- Between 2004-2013, the arithmetic average of the RCA coefficients for the 10 years,
- Between 2014-2023, the arithmetic average of the RCA coefficients for 10 years,
- Degree of Superiority: Indicates the degree of superiority (disadvantage, weak superiority, moderate superiority, and strong superiority) according to the appropriate average RCA values.
- Product Code (PC)
- Trimmed Mean (TM)
- Degree of Superiority (DS)
- Average (Av.)

The RCA coefficients calculated for the export of wheat and meslin, maize (corn), and rice for selected countries and Türkiye in world exports have been tabulated both periodically and in TM form.

Additionally, the TM RCA indices have been classified according to their superiority levels and displayed in the last column of the table.

3.1. Competitiveness of the Top 20 Countries in World Wheat and Meslin Exports

The TM values of the RCA coefficients, showing the competitive situation in the global market for the top 20 countries, including Türkiye, in the world wheat and meslin export ranking, are presented in Table 2.

According to the TM values, 15 out of 20 countries seem to have a competitive advantage in the wheat and meslin export market. However, among these 15 countries, 10 have a strong competitive advantage, 2 have a moderate competitive advantage and 3 have a weak competitive advantage. While 15 countries can compete in the global market for wheat and meslin exports, 5 countries (Poland, Germany, Brazil, United Kingdom and Türkiye) are at a competitive disadvantage.

Table 2. The RCA index values of the top 20 countries in world wheat and meslin exports

Ranking	Country	PC	2004-2013 Av.	2014-2023 Av.	TM	DS
1	Russia	'1001	2.82	6.26	4.45	Strong Superiority
2	Australia	'1001	9.73	7.67	8.53	Strong Superiority
3	Canada	'1001	4.95	5.67	5.34	Strong Superiority
4	USA	'1001	2.63	1.62	2.12	Moderate Superiority
5	France	'1001	3.65	3.36	3.41	Moderate Superiority
6	Ukraine	'1001	9.00	27.73	18.42	Strong Superiority
7	Romania	'1001	2.95	7.29	5.20	Strong Superiority
8	Poland	'1001	0.54	1.42	0.96	Disadvantage
9	Germany	'1001	0.58	0.54	0.56	Disadvantage
10	Kazakhstan	'1001	6.76	7.77	7.31	Strong Superiority
11	Bulgaria	'1001	7.29	11.43	9.56	Strong Superiority
12	Lithuania	'1001	4.88	8.65	6.78	Strong Superiority
13	Argentina	'1001	12.63	12.53	12.75	Strong Superiority
14	Hungary	'1001	1.88	1.96	1.92	Weak Superiority
15	CR*	'1001	0.88	1.13	1.03	Weak Superiority
16	Brazil	'1001	0.52	0.42	0.46	Disadvantage
17	Türkiye	'1001	0.25	0.20	0.19	Disadvantage
18	Latvia	'1001	7.28	13.45	10.53	Strong Superiority
19	Slovakia	'1001	0.75	1.23	1.01	Weak Superiority
20	UK**	'1001	0.48	0.22	0.34	Disadvantage

PC= product code, TM= trimmed mean, DS= degree of superiority, Av.= average, *CR: Czech Republic **UK: United Kingdom.

In the global market for wheat and meslin exports, the countries with strong dominance are Ukraine (18.42), Argentina (12.75), Latvia (10.53), Bulgaria (9.56), Australia (8.53), Kazakhstan (7.31), Lithuania (6.78), Canada (5.34), Romania (5.20), and Russia (4.45). The country with the highest competitive advantage in the global market is Ukraine. Additionally, Ukraine's increase in its RCA value from 9.00 in the 2004-2013 period to 27.73 in the 2014-2023 period indicates a significant competitive advantage in the global wheat and meslin export market. The top three countries that increased their competitive advantage in the second period compared to the first period are Ukraine (+9.42), Latvia (+3.25), and Bulgaria (+2.27). On the contrary, the first top three countries that lost competitive strength in the second period compared to the first period are. For Türkiye, whose population is increasing above the world average, this situation indicates that urgent intervention is necessary. Türkiye (During the 2004-2023 period, the area of agricultural land in Türkiye decreased faster than the world average (7.57%), while its population increased more than the world average (24.40%) (World Bank, 2024) is the most disadvantaged country in the global competition in the wheat and meslin export market according to the TM value. In the RCA analysis covering the period from 2004 to 2023, Türkiye's RCA value for the period from 2004 to 2013 decreased from 0.25 to 0.20 in the period from 2014 to 2023. This decline in Türkiye's RCA value indicates that Türkiye has been gradually losing its competitive edge in the global wheat and meslin export market during the 2004-2023 period.

The NEI results showing the commercial performance of the top 20 countries leading in wheat and meslin exports in the global market are presented in Table 3.

Table 3. The NEI values of the top 20 countries in world wheat and meslin exports

Ranking	Country	PC	2004-2013 Av.	2014-2023 Av.	TM	DS
1	Russia	'1001	0.89	0.97	0.95	Specialization Exists
2	Australia	'1001	1.00	0.98	1.00	Specialization Exists
3	Canada	'1001	0.99	0.99	0.99	Specialization Exists
4	USA	'1001	0.85	0.81	0.83	Specialization Exists
5	France	'1001	0.95	0.94	0.95	Specialization Exists
6	Ukraine	'1001	0.94	1.00	1.00	Specialization Exists
7	Romania	'1001	0.31	0.72	0.58	Specialization Exists
8	Poland	'1001	0.06	0.70	0.40	Specialization Exists
9	Germany	'1001	0.40	0.29	0.35	Specialization Exists
10	Kazakhstan	'1001	0.99	0.88	0.95	Specialization Exists
11	Bulgaria	'1001	0.89	0.97	0.95	Specialization Exists
12	Lithuania	'1001	0.85	0.92	0.90	Specialization Exists
13	Argentina	'1001	1.00	1.00	1.00	Specialization Exists
14	Hungary	'1001	0.93	0.84	0.89	Specialization Exists
15	CR*	'1001	0.91	0.95	0.94	Specialization Exists
16	Brazil	'1001	-0.77	-0.71	-0.75	No Specialization
17	Türkiye	'1001	-0.65	-0.92	-0.84	No Specialization
18	Latvia	'1001	0.61	0.60	0.62	Specialization Exists
19	Slovakia	'1001	0.62	0.93	0.79	Specialization Exists
20	UK**	'1001	0.07	-0.36	-0.14	Specialization Exists

PC= product code, TM= trimmed mean, DS= degree of superiority, Av.= average, *CR: Czech Republic **UK: United Kingdom.

According to the analysis, 17 of the 20 countries have positive NEI values, while 3 countries have negative NEI values. The positive values in the analysis indicate that the relevant countries are net exporters in the wheat and meslin foreign trade, while the negative values show that they are net importers. Among the countries with negative values, Brazil, Türkiye, and the United Kingdom, Türkiye has the highest negative TM value. This means that the Kingdom is actually a net importer in the wheat and meslin foreign trade. Positive NEI values may indicate that the relevant countries contribute positively to the export of wheat and meslin and their trade balances.

The results of the EIRI analysis for the top 20 countries in the world wheat and meslin export ranking, which primarily measures intra-industry trade and provides information about the country's own trade performance, are shown in Table 4.

The EIRI analysis results indicate that Brazil and Türkiye are at a disadvantage in wheat and meslin exports. Additionally, the table shows that Argentina, Australia, and Ukraine have the highest advantages in wheat and meslin exports. The high EIRI values of Argentina, Australia, and Ukraine indicate that these countries have a higher export performance rather than importing wheat and meslin. However, the average RCA values of Argentina and Australia for 2014-2023 are lower than their average RCA values for 2004-2013. Ukraine's average RCA value for 2014-2023 is higher than its average RCA value for 2004-2013.

Table 4. The EIRI values of the top 20 countries in world wheat and meslin exports

Ranking	Country	PC	2004-2013 Av.	2014-2023 Av.	TM	DS
1	Russia	'1001	965.85	128.23	267.60	Competitive Advantage
2	Australia	'1001	102751.16	30171.80	50867.45	Competitive Advantage
3	Canada	'1001	791.33	300.00	521.03	Competitive Advantage
4	USA	'1001	23.86	14.33	18.06	Competitive Advantage
5	France	'1001	73.25	59.40	64.98	Competitive Advantage
6	Ukraine	'1001	1395.76	1786.00	1541.41	Competitive Advantage
7	Romania	'1001	5.93	9.30	7.54	Competitive Advantage
8	Poland	'1001	2.43	8.77	5.31	Competitive Advantage
9	Germany	'1001	3.84	2.60	3.16	Competitive Advantage
10	Kazakhstan	'1001	1220.81	132.39	560.46	Competitive Advantage
11	Bulgaria	'1001	103.06	99.71	100.12	Competitive Advantage
12	Lithuania	'1001	31.84	44.17	35.82	Competitive Advantage
13	Argentina	'1001	59742.29	51995.12	51581.09	Competitive Advantage
14	Hungary	'1001	65.26	17.93	36.17	Competitive Advantage
15	CR*	'1001	48.36	53.17	49.78	Competitive Advantage
16	Brazil	'1001	0.23	0.27	0.23	Competitive Disadvantage
17	Türkiye	'1001	0.73	0.06	0.25	Competitive Disadvantage
18	Latvia	'1001	9.16	5.94	7.19	Competitive Advantage
19	Slovakia	'1001	9.93	46.91	26.68	Competitive Advantage
20	UK**	'1001	2.15	0.77	1.42	Competitive Advantage

PC= product code, TM= trimmed mean, DS= degree of superiority, Av.= average, *CR: Czech Republic **UK: United Kingdom.

These findings regarding Argentina, Australia, and Ukraine indicate that Argentina and Australia's competitive advantages in the global wheat and meslin export market have diminished, while Ukraine's competitiveness has increased. Additionally, the table indicates that during the 2004-2023 period, 7 of the top 20 countries in the world wheat and meslin export market increased their competitive strength, while 13 of them saw a decrease in their competitiveness. The countries that have lost competitiveness are Russia, Australia, Canada, the USA, France, Germany, Kazakhstan, Bulgaria, Argentina, Hungary, Latvia, and the United Kingdom, while the countries that have increased their competitiveness are Ukraine, Romania, Poland, Lithuania, the Czech Republic, Brazil, and Slovakia.

3.2. Competitiveness of the Top 20 Countries in World Maize (Corn) Exports

The TM values of the RCA coefficients, which show the competitive situation in the global market for the top 20 countries in the world maize (corn) export ranking, where Türkiye ranks 10th, are shown in Table 5. According to TM values, 12 out of the 20 countries in the maize (corn) export market appear to have a competitive advantage. However, among the 12 countries with a competitive advantage, 8 have a strong, 3 have a moderate, and 1 has a weak competitive advantage. While 12 countries can compete in the global maize (corn) export market, 6 countries (Poland, Russia, Türkiye, Canada, Pakistan, and Austria) are at a competitive disadvantage. 2 countries (Myanmar and Serbia) could not have their RCA index value calculated due to missing data.

Argentina (34.45), Ukraine (28.78), Paraguay (24.57), Brazil (9.67), Romania (6.22), Hungary (4.52), Bulgaria (4.36), USA (4.32), respectively. The country with the highest competitive advantage in the global market is Argentina, which increased its RCA value from 28.66 in the period 2004-2013 to 40.41 in the period 2014-2023, indicating a further increase in its competitive advantage in the global maize (corn) export market. The top 3 countries that increased their competitive advantage in the second period compared to the first period are Ukraine (+32.92), Argentina (+11.75) and Brazil (+2.27). Conversely, Hungary (-1.78), USA (-1.42) and India (-1.05) are the top 3 countries that lost competitive advantage in the second period compared to the first period. These results indicate that while 3 countries (Ukraine, Argentina, Brazil) have become more competitive in the global maize (corn) export market, the other 3 countries (Hungary, USA, India) have lost competitiveness in the global market. Türkiye slightly increased its competitiveness in the maize (corn) export market slightly by increasing its RCA value (0.06) in the second period compared to the first period. However, according to the TM value, Türkiye remains the most disadvantaged country in global competition in the maize (corn) export market.

The NEI results showing the commercial performance of the top 20 countries leading in maize (corn) exports in the global market are presented in Table 6. According to the analysis, 16 out of the 20 countries have positive NEI values, while 2 countries have negative NEI values. The NEI index value could not be calculated for Myanmar and Serbia due to missing data positive values in the analysis indicate that the respective countries are net exporters in maize (corn) foreign trade, while the negative values indicate that they are net importers.

Table 5. The RCA index values of the top 20 countries in world maize (corn) exports

Ranking	Country	PC	2004-2013 Av.	2014-2023 Av.	TM	DS
1	USA	'1005	5.03	3.61	4.32	Strong Superiority
2	Brazil	'1005	6.53	12.75	9.67	Strong Superiority
3	Argentina	'1005	28.66	40.41	34.45	Strong Superiority
4	Ukraine	'1005	12.60	45.52	28.78	Strong Superiority
5	France	'1005	2.52	1.69	2.08	Moderate Superiority
6	Romania	'1005	4.20	8.14	6.22	Strong Superiority
7	Poland	'1005	0.30	0.76	0.50	Disadvantage
8	South Africa	'1005	3.43	2.96	3.25	Moderate Superiority
9	Russia	'1005	0.14	0.94	0.51	Disadvantage
10	Türkiye	'1005	0.23	0.39	0.26	Disadvantage
11	Canada	'1005	0.30	0.42	0.36	Disadvantage
12	Paraguay	'1005	25.65	23.64	24.57	Strong Superiority
13	Hungary	'1005	5.45	3.67	4.52	Strong Superiority
14	India	'1005	1.71	0.66	1.14	Weak Superiority
15	Myanmar	'1005	0.00	0.00	0.00	2004-2010 missing data
16	Bulgaria	'1005	3.76	5.10	4.36	Strong Superiority
17	Pakistan	'1005	0.71	1.20	0.77	Disadvantage
18	Austria	'1005	0.66	0.67	0.67	Disadvantage
19	Serbia	'1005	0.00	0.00	0.00	2004-2005 missing data
20	Croatia	'1005	1.94	4.43	3.16	Moderate Superiority

PC= product code, TM= trimmed mean, DS= degree of superiority, Av.= average.

Table 6. The NEI values of the top 20 countries in world maize (corn) exports

Ranking	Country	PC	2004-2013 Av.	2014-2023 Av.	TM	DS
1	USA	'1005	0.89	0.92	0.92	Specialization Exists
2	Brazil	'1005	0.80	0.90	0.87	Specialization Exists
3	Argentina	'1005	0.99	0.99	0.99	Specialization Exists
4	Ukraine	'1005	0.78	0.93	0.87	Specialization Exists
5	France	'1005	0.76	0.70	0.73	Specialization Exists
6	Romania	'1005	0.36	0.66	0.54	Specialization Exists
7	Poland	'1005	-0.34	0.26	-0.02	No Specialization
8	South Africa	'1005	0.59	0.62	0.66	Specialization Exists
9	Russia	'1005	-0.29	0.63	0.21	Specialization Exists
10	Türkiye	'1005	-0.55	-0.58	-0.60	No Specialization
11	Canada	'1005	-0.34	-0.18	-0.27	No Specialization
12	Paraguay	'1005	0.70	0.75	0.74	Specialization Exists
13	Hungary	'1005	0.86	0.63	0.76	Specialization Exists
14	India	'1005	0.98	0.79	0.91	Specialization Exists
15	Myanmar	'1005	-	0.85	-	2004-2009 missing data
16	Bulgaria	'1005	0.38	0.67	0.55	Specialization Exists
17	Pakistan	'1005	-0.47	-0.35	-0.44	No Specialization
18	Austria	'1005	0.14	-0.07	0.03	Specialization Exists
19	Serbia	'1005	-	0.87	-	2004-2005 missing data
20	Croatia	'1005	0.27	0.58	0.46	Specialization Exists

PC= product code, TM= trimmed mean, DS= degree of superiority, Av.= average.

Among the countries with negative values, Poland, Türkiye, Canada, and Pakistan, Türkiye has the highest negative TM value. These results mean that Türkiye, Poland, Canada, and Pakistan are actually net importer countries in maize (corn) foreign trade. Positive NEI values may mean that the relevant countries' maize (corn) exports positively contribute to their foreign trade balances. The negative situation in the NEI values of Poland, Türkiye, Canada, and Pakistan regarding maize (corn) trade may mean a negative contribution to global export competitiveness.

The analysis results conducted with EIRI for the top 20 countries in the world maize (corn) export ranking, which measures intra-industry trade and provides information about the country's own trade performance, are shown in Table 7. The EIRI analysis results show that Türkiye and Canada are at a disadvantage in maize (corn) exports. Additionally, the table shows that Argentina, India, and the USA have the highest advantages in maize (corn) exports. The high EIRI values of Argentina, India, and the USA indicate that these countries have a higher export performance in maize (corn) rather than import.

Argentina's average RCA value for 2014-2023 is greater than its average RCA value for 2004-2013. This increase in the RCA value means that Argentina's competitiveness in global maize (corn) exports has further increased. In the maize (corn) export market, India's average RCA value decreased from 349.55 in the 2004-2013 period to 60.70 in the 2014-2023 period, while the USA's RCA value declined from 44.50 to 40.09 during the same period. These findings regarding India and the USA indicate that the competitive advantage of India and the USA in the global maize (corn) export market has diminished. India has significantly reduced its competitiveness in the global maize (corn) market during the 2014-2023 period. Additionally, the table indicates that 12 of the top 20 countries in global maize (corn) exports from 2004-2023 have increased their competitiveness, while 8 have seen a decline in their competitiveness. Countries losing competitiveness include the USA, France, South Africa, Türkiye, Paraguay, Hungary, India, and Austria, while countries gaining competitiveness are Brazil, Argentina, Ukraine, Romania, Poland, Russia, Canada, Myanmar, Bulgaria, Pakistan, Serbia, and Croatia.

Table 7. The EIRI values of the top 20 countries in world maize (corn) exports

Ranking	Country	PC	2004-2013 Av.	2014-2023 Av.	TM	DS
1	USA	'1005	44.50	40.09	42.35	Competitive Advantage
2	Brazil	'1005	26.66	47.40	32.00	Competitive Advantage
3	Argentina	'1005	312.63	362.36	327.97	Competitive Advantage
4	Ukraine	'1005	16.04	58.42	33.89	Competitive Advantage
5	France	'1005	12.27	7.92	10.04	Competitive Advantage
6	Romania	'1005	5.06	6.97	6.09	Competitive Advantage
7	Poland	'1005	1.07	2.59	1.73	Competitive Advantage
8	South Africa	'1005	32.83	24.39	25.99	Competitive Advantage
9	Russia	'1005	2.01	6.42	3.72	Competitive Advantage
10	Türkiye	'1005	0.78	0.44	0.42	Competitive Disadvantage
11	Canada	'1005	1.00	1.01	0.93	Competitive Disadvantage
12	Paraguay	'1005	10.99	10.40	10.53	Competitive Advantage
13	Hungary	'1005	23.87	7.64	14.66	Competitive Advantage
14	India	'1005	349.55	60.70	172.77	Competitive Advantage
15	Myanmar	'1005	-	20.76	-	Missing Data
16	Bulgaria	'1005	6.58	8.03	7.19	Competitive Advantage
17	Pakistan	'1005	1.06	1.47	1.03	Competitive Advantage
18	Austria	'1005	2.25	1.20	1.68	Competitive Advantage
19	Serbia	'1005	-	28.46	-	Missing Data
20	Croatia	'1005	4.43	5.42	4.94	Competitive Advantage

PC= product code, TM= trimmed mean, DS= degree of superiority, Av.= average.

3.3. Competitiveness of the Top 20 Countries in Global Rice Exports

In the ranking of the top 20 countries exporting rice in the world, Türkiye ranks 19th. The TM values of the RCA coefficients, which show the competitive situation in the global market for the top 20 rice-exporting countries, are presented in Table 8. According to TM values, 12 out of 20 countries in the rice export market appear to have a competitive advantage. However, among the 12 countries with a competitive advantage, 9 have a strong competitive advantage, while 3 have a weak competitive advantage. In the global market for rice exports, 12 countries are competitive, while 6 countries (China, Belgium, Netherlands, Austria, Spain, Türkiye) are at a disadvantage in the competition. The RCA index value could not be calculated for 2 countries (Myanmar and Djibouti) due to missing data. Countries with a strong dominance in the global rice export market are as follows: Guyana (86.87), Pakistan (63.87), Uruguay (46.68), Vietnam (19.75), Thailand (17.47), India (15.79), Paraguay (12.74), and Tanzania (4.26). The country with the highest competitive advantage in the global market is Guyana. However, the decrease in its RCA value from 104.66 in the 2004-2013 period to 68.18 in the 2014-2023 period indicates that it is gradually losing its competitive advantage in the global rice export market. The top three countries that increased their competitive advantage in the second period compared to the first period are Cambodia (17.92), Paraguay (12.78), and Tanzania (8.61). Conversely the top three countries that lost competitiveness in the second period compared to the first period are Guyana (-36.43), Vietnam (-22.92), and Uruguay (-14.25). These results show that while the competitiveness of three countries (Cambodia, Paraguay, Tanzania) in the global rice export market has increased, the other three countries (Guyana, Vietnam, Tanzania) have lost competitiveness in the global market. Türkiye, on the other hand, slightly enhanced its competitiveness in the rice export market by increasing its RCA value by 0.20 in the second period compared to the first period. However, according to the TM value, Türkiye is the second most disadvantaged country in the global rice export market after Austria.

The NEI results showing the commercial performance of the top 20 countries leading in rice exports in the global market are presented in Table 9.

Table 8. The RCA index values of the top 20 countries in world rice exports

Ranking	Country	PC	2004-2013 Av.	2014-2023 Av.	TM	DS
1	India	‘1006	13.58	17.6	15.79	Strong Superiority
2	Thailand	‘1006	21.57	13.84	17.47	Strong Superiority
3	Viet Nam	‘1006	31.81	8.89	19.75	Strong Superiority
4	Pakistan	‘1006	59.28	63.68	63.87	Strong Superiority
5	USA	‘1006	1.27	0.83	1.05	Weak Superiority
6	Cambodia	‘1006	6.71	24.63	14.41	Strong Superiority
7	China	‘1006	0.27	0.2	0.23	Disadvantage
8	Italy	‘1006	1.1	0.93	1.01	Weak Superiority
9	Myanmar	‘1006	-	-	-	2004-2010 missing data
10	Brazil	‘1006	0.92	1.27	1.11	Weak Superiority
11	Uruguay	'1006	53.99	39.74	46.68	Strong Superiority
12	Belgium	'1006	0.46	0.52	0.48	Disadvantage
13	Paraguay	'1006	6.34	19.12	12.74	Strong Superiority
14	Netherland	'1006	0.23	0.33	0.28	Disadvantage
15	Austria	'1006	0.02	0.03	0.03	Disadvantage
16	Djibouti*	'1006	-	-	-	-
17	Guayana	'1006	104.61	68.18	86.87	Strong Superiority
18	Spain	'1006	0.58	0.43	0.49	Disadvantage
19	Türkiye	'1006	0.18	0.38	0.27	Disadvantage
20	Tanzania	'1006	1.44	10.05	4.26	Strong Superiority

PC= product code, TM= trimmed mean, DS= degree of superiority, Av.= average, * the data obtained is from the years of 2009-2021-2022 and 2023 only.

Table 9. The NEI values of the top 20 countries in world rice exports

Ranking	Country	PC	2004-2013 Av.	2014-2023 Av.	TM	DS
1	India	'1006	1.00	1.00	1.00	Specialization Exists
2	Thailand	'1006	1.00	0.99	1.00	Specialization Exists
3	Wiet Nam	'1006	0.97	0.86	0.93	Specialization Exists
4	Pakistan	'1006	0.98	0.97	0.98	Specialization Exists
5	USA	'1006	0.55	0.30	0.43	Specialization Exists
6	Cambodia	'1006	0.23	0.96	0.64	Specialization Exists
7	China	'1006	0.07	-0.39	-0.17	No Specialization
8	Italy	'1006	0.74	0.57	0.66	Specialization Exists
9	Myanmar	'1006	-	1.00	-	2004-2009 missing data
10	Brazil	'1006	-0.23	0.14	-0.01	No Specialization
11	Uruguay	'1006	1.00	0.99	0.99	Specialization Exists
12	Belgium	'1006	-0.01	-0.06	-0.04	No Specialization
13	Paraguay	'1006	0.94	0.99	0.98	Specialization Exists
14	Netherland	'1006	-0.14	-0.04	-0.08	No Specialization
15	Australia	'1006	-0.08	-0.01	-0.03	No Specialization
16	Djibouti*	'1006	-	-	-	-
17	Guayana	'1006	1.00	1.00	1.00	Specialization Exists
18	Spain	'1006	0.37	0.18	0.29	Specialization Exists
19	Türkiye	'1006	-0.72	-0.46	-0.59	No Specialization
20	Tanzania	'1006	-0.42	0.48	0.03	No Specialization

PC= product code, TM= trimmed mean, DS= degree of superiority, Av.= average, * the data obtained is from the years of 2009-2021-2022 and 2023 only.

According to the analysis, the NEI values of 12 out of the 20 countries appear positive, while the NEI values of 6 countries are negative. The NEI index value could not be calculated for Myanmar and Djibouti due to missing data positive values in the analysis indicate that the respective countries are net exporters in rice foreign trade, while the negative values indicate that they are net importers. The countries with negative values are China, Brazil, Belgium, the Netherlands, Australia, and Türkiye. Among these countries, the one with the highest negative TM value is Türkiye. These results mean that China, Brazil, Belgium, the Netherlands, Australia, and Türkiye are net importing countries in rice foreign trade. Positive NEI values may indicate that the relevant countries contribute positively to rice exports and trade balances. Conversely the negative NEI values of China, Brazil, Belgium, the Netherlands, Australia, and Türkiye in rice trade may indicate a negative contribution to global export competitiveness.

The analysis results of the top 20 countries in the world rice export ranking, which measures more intra-industry trade and provides information about the country's own trade performance, using EIRI, are shown in Table 10. According to the EIRI TM values, the analysis results show that Australia and Türkiye are at a disadvantage in rice exports. Additionally, it is understood that India, Thailand, and Uruguay have the highest advantage in rice exports according to the TM values in the table. The high EIRI values of India, Thailand, and Uruguay indicate that these countries have a strong performance in rice exports. However, India's average RCA value decreased from 163369.94 in the 2004-2013 period to 4399.32 in the 2014-2023 period, and Thailand's RCA value decreased from 2426.54 to 572.31 in the same period. These findings regarding India and Thailand indicate that their competitive advantage in the global rice export market has significantly decreased during the 2004-2023 period. Additionally, the table indicates that during the 2004-2023 period, 9 of the top 20 countries in global rice exports have increased their competitive strength, while 10 have seen a decrease in their competitiveness. The EIRI value for the country of Djibouti could not be calculated due to missing data. Countries that have increased their competitiveness are Cambodia, Myanmar, Brazil, Paraguay, Netherlands, Australia, Guyana, Türkiye, and Tanzania, while countries that have lost competitiveness are India, Thailand, Vietnam.

The index results for the top 20 leading exporters of wheat and meslin, maize (corn) and rice products in the global market are evaluated together with the results of similar studies previously conducted for India, Pakistan and Kazakhstan.

Geetha and Srivastava (2018), using the RCA Index and Regression Analysis, found that the quantity and value of India’s maize exports recorded significant growth in the post-WTO period (1996-2016), but exhibited an unstable Outlook.

Table 10. The EIRI values of the top 20 countries in world rice exports

Ranking	Country	PC	2004-2013 Av.	2014-2023 Av.	UO	DS
1	India	'1006	163369.94	4399.32	20922.97	Competitive Advantage
2	Thailand	'1006	2426.54	572.31	1220.98	Competitive Advantage
3	Viet Nam	'1006	91.14	58.43	76.63	Competitive Advantage
4	Pakistan	'1006	1169.49	92.91	507.70	Competitive Advantage
5	USA	'1006	5.58	2.65	4.04	Competitive Advantage
6	Cambodia	'1006	16.00	112.03	50.59	Competitive Advantage
7	China	'1006	2.23	0.62	1.34	Competitive Advantage
8	Italy	'1006	10.69	5.07	7.83	Competitive Advantage
9	Myanmar	'1006		1669.60		2004-2009 missing data
10	Brazil	'1006	1.32	1.95	1.61	Competitive Advantage
11	Uruguay	'1006	1656.21	468.76	905.04	Competitive Advantage
12	Belgium	'1006	1.57	1.21	1.38	Competitive Advantage
13	Paraguay	'1006	119.70	443.47	260.81	Competitive Advantage
14	Netherlands	'1006	1.21	1.27	1.26	Competitive Advantage
15	Australia	'1006	0.16	0.17	0.16	Competitive Disadvantage
16	Djibouti*	'1006	-	-	-	-
17	Guyana**	'1006	33037249.86	2285.69	488.46	Competitive Advantage
18	Spain	'1006	3.65	2.12	2.88	Competitive Advantage
19	Türkiye	'1006	0.33	0.51	0.41	Competitive Disadvantage
20	Tanzania	'1006	5.43	2020.10	451.46	Competitive Advantage

PC= product code, TM= trimmed mean, DS= degree of superiority, Av.= average, * Missing data (there is data from 2009-2021-2022-2023). ** The import value for 2008-2009 is "0". To calculate the index value, the values for the years 2008 and 2009 have been entered as "0.001".

They stated that increases in domestic maize (corn) production increases led to the development of maize exports. Nithyashree et al. (2020), on the other hand, pointed out that the decline in India's maize exports and the increase in maize imports have negatively affected the balance of trade over time and predicted an increase in India's imports, especially for cereals, in the future. The results of the analyses in this study covering the period 2004-2023 seem to confirm the findings of Geetha and Srivastava (2018) and Nithyashree et al. (2020). According to the NEI and EIRI analysis results, India has a high export performance in maize foreign trade and is a net exporter. However, the RCA analysis indicates that India has lost significant strength in global competition in maize exports during the period 2014-2023 compared to 2004-2013, suggesting a weak competitive advantage in the global maize export market.

Govindasamy et al. (2023) examined the competitiveness of wheat, maize (corn), rice, sugar cane and cotton, which are important agricultural products grown in Pakistan. They stated that Pakistan has a share in the world production of sugar cane and cotton, with rice being added to these products in recent years. However, they stated that Pakistan uses these products domestically rather than foreign trade and is very sensitive in terms of imports of these 5 agricultural products, showing a relative import advantage (RMA) in some years from 2001 to 2021. In this study, which analyses the competitiveness of the top 20 leading exporters of wheat and meslin, maize (corn) and rice in the global market, Pakistan was excluded from the analysis since it is not among the top 20 countries in wheat and meslin exports. However, ranking 17th in the maize (corn) export market and 4th in rice exports, Pakistan is among the leading countries in the global rice export market. Pakistan uses wheat and meslin and maize (corn) primarily to meet domestic demand and according to the RCA index results, Pakistan is disadvantaged in global competition in the maize (corn) export market. However, Pakistan has gained significant strength in global competition in maize exports in the 2014-2023 period compared to the 2004-2013 period. According to the results of NEI analysis, Pakistan is a net importer country in maize (corn) foreign trade contributing negatively to the foreign trade balance. According to the results of EIRI analysis, it is understood that Pakistan has increased its competitiveness in the global maize (corn) export market. According to the results of RCA index, Pakistan has a competitive advantage in rice exports in the global market NEI and EIRI analyses show that Pakistan has a high export performance in rice foreign trade and is a net exporter. In this study covering the period 2004-2023, the results of maize (corn) and rice analyses of Pakistan seem to confirm the findings of Govindasamy et al. (2023).

Bashimov (2022) determined that Kazakhstan has a comparative and competitive advantage especially in wheat and barley exports. In this study, which analyses the competitiveness of the top 20 leading exporters of wheat and meslin, maize (corn) and rice in the global market, Kazakhstan ranks 10th in global exports of wheat and meslin. According to the results of the RCA index, Kazakhstan has an advantageous position in the global market competition in wheat and meslin exports. According to the results of NEI analysis, Kazakhstan is a net exporter in wheat and meslin foreign trade and contributing positively to the foreign trade balance. According to the results of EIRI analysis, Kazakhstan has a competitive advantage in the global wheat and meslin export market, although it has slightly lost competitive power during the period 2014-2023 compared to the 2004-2013. In this study covering the period 2004-2023, the wheat and meslin analysis results of Kazakhstan confirm the findings of Bashimov (2022).

4. Conclusion

The importance of trade in the global economy has been continuously increasing from the past to the present. However, as agricultural areas shrink, the increasing world population, decreasing agricultural land areas, and the climate crisis have made the trade of agricultural products such as wheat and meslin, maize (corn), and rice, which meet more than half of the daily energy needs of the world's population, even more important. Countries that can effectively adapt to the changing global trade environment are achieving greater success in the global economy and increasing the intensity of competition in the trade of these products. In today's world economy, the conditions of fierce competition necessitate that trade be shaped solely based on advantages. This approach can help countries achieve their economic growth and development goals by utilizing their competitive advantages.

The study was conducted to reveal the competitiveness of the top 20 countries in the global wheat and meslin, maize (corn), and rice export market during the 2004-2023 period. Data for the period 2004-2023 concerning the 20 countries were obtained from the Trade Map database, and analyses were conducted using RCA, NEI, and EIRI. The top twenty exporters account for 95.53% of global wheat and meslin exports, 95.62% of maize (corn) exports, and 95.28% of rice exports. Ukraine, the country with the highest RCA index value in the global wheat and meslin export market, is a net exporting country according to the NEI value. While Australia and Argentina, the leaders of the global market from 2004 to 2023, have lost their competitive edge, Ukraine has become the country that has increased its competitive advantage the most. Ranking 17th in the global wheat and meslin export market, Türkiye is the most disadvantaged country in the global competition of the wheat and meslin export market according to the RCA index value. According to the NEI value, Türkiye is in the position of a net importer of wheat and meslin. Türkiye, which reduced its EIRI value from the 2004-2013 period to the 2024-2023 period, is the most disadvantaged country in global competition. Argentina, the country with the highest RCA index value in the global maize (corn) export market, is a net exporter according to the NEI value. During the period from 2004 to 2023, while India and the USA, the leaders of the global market, lost competitive strength (especially India), Argentina became the country that increased its competitive advantage the most. Türkiye, ranked 10th in the global maize (corn) export market, is the most disadvantaged country in the global competition of the maize (corn) export market according to the RCA index value. According to the NEI value, Türkiye is a net maize (corn) importing country. Türkiye, which reduced its EIRI value in the 2024-2023 period compared to the 2004-2013 period, is the most disadvantaged country in global competition. The country with the highest RCA index value in the global rice export market, Guyana, is a net exporter according to the NEI value, and according to the EIRI value, Guyana was the leader in the global market from 2004 to 2023. Meanwhile, India and Thailand have lost their competitive power, while Tanzania has increased its competitive advantage the most. Ranking 19th in the global rice export market, Türkiye is the second most disadvantaged country after Austria in the global competition of the rice export market according to the RCA index value. According to the NEI value, Türkiye is a net rice importer. Türkiye, although it has increased its EIRI value in the 2024-2023 period compared to the 2004-2013 period, is a country at a disadvantage in global competition.

As a country known for its agriculture, Türkiye appears to be at a disadvantage in the global export market for wheat and meslin, maize (corn), and rice. With a population growing above the world average, rapidly decreasing agricultural land, and the global climate crisis considered the most significant issue of the century, Türkiye's dependence on imports for these three agricultural products seems to impose a financial burden on the economy, potentially causing serious economic loss for the country. The government has a great responsibility to find solutions to the problems encountered in the production of these products, which hold an important place in human nutrition. Otherwise, the foreign trade balance of these three products will be negatively affected. In this context, the urgent completion of consolidation works on fragmented and scattered agricultural lands throughout Türkiye is essential to reduce the costs of agricultural products and prevent major economic losses. This will significantly benefit producers, particularly in foreign trade. Policies supporting wheat and meslin, rice and maize cultivation and seed production will not only provide a competitive advantage in the global market, but also reduce import consumption. It is also of great importance to prepare support programmes for the export processes of wheat and meslin, rice and maize products. Support for producers and exporters should cover areas such as promoting new production technologies to increase productivity, addressing inefficiencies in the supply chain and optimising costs. Preventing increases in fertiliser and diesel prices is also an important cost factor for producers, state measures in these areas will ensure the sustainability of agricultural production. Moreover, improving the efficiency and quality standards of domestic production is necessary to remain competitive in foreign markets. Increasing export volume, finding new markets and strengthening relations with existing markets will be important factors in increasing the export to imports ratio. In summary, there is a need for appropriate proactive interventions to favourably affect the balance of trade, particularly in wheat and meslin, rice and maize trade, and agricultural trade in general.

Author Contributions

The percentages of the author' contributions are presented below. The author reviewed and approved the final version of the manuscript.

	Z.A.Ç.
C	100
D	100
S	100
DCP	100
DAI	100
L	100
W	100
CR	100
SR	100
PM	100
FA	100

C=Concept, D= design, S= supervision, DCP= data collection and/or processing, DAI= data analysis and/or interpretation, L= literature search, W= writing, CR= critical review, SR= submission and revision, PM= project management, FA= funding acquisition.

Conflict of Interest

The author declared that there is no conflict of interest.

Ethical Consideration

Ethics committee approval was not required for this study because of there was no study on animals or humans.

References

Aktaş Çimen Z, Sarıçoban K. 2024. Türkiye'nin süs bitkileri ihracatındaki rekabet gücü. Uluslararası İktisadi İdari İnc Derg, 44: 151-168.

Amighini A. 2004. China in the International fragmentation of production: Evidence from the ICT İndustry. Università commerciale Luigi Bocconi, Milano, Italy, pp: 147.

Asciuto A, Carapezza R, Galati A, Schimmenti E. 2008. The competitiveness of the Italian flower andornamental plant sector. New Medit, 7(1): 26-37.

Aysu A. 2018. Buğday: beslenme kültürü ve politikalar. Meltem İzmir Akdeniz Akad Derg, 4: 82-90.

Balassa B, Noland M. 1989. Revealed comparative advantage in Japan and the United States. J Int Econ Integrat, 4(2): 8-22.

Balassa B. 1965. Trade liberalisation and “revealed” comparative advantage. Manchester School, 33(2): 99-123.

Balassa B. 1977. Revealed comparative advantage revisited: An analysis of relative export shares of the industrial countries, 1953–1971. Manchester School, 45(4): 327-344.

Banterle A, Carraresi L. 2007. Competitive performance analysis and European Union trade: The case of the prepared swine meat sector. Acta Agri Scand Section C, 4(3): 159-172.

Bashimov G. 2018. Kazakistan’ın bakır sektöründeki rekabet gücünün ölçülmesi. Ekon Sos Araş Derg, Özel Sayı, 55-68.

Bashimov G. 2022. Kazakistan’ın hububat ürünleri ihracatında karşılaştırmalı üstünlüğünün ölçülmesi. Asya Araş Uluslar Sos Bil Derg, 6 (2): 87-198.

Bin Rahman AR, Zhang J. 2023. Trends in rice research: 2030 and beyond. Food Ener Secur, 12(2): e390.

Can MB. 2023. Mısır ve buğday glüteninin ruminant beslemede kullanımı. Hayvansal Üretim, 64(2): 93-102.

Cornejo R, Singh S, Harris J. 2023. Do revisions to the harmonized system lead to distortions in rules of origin? A case study of India’s selected free trade agreements. Legal Issues Econ Integrat, 50(2): 185-210.

Erbaş Köse ÖD, Mut Z. 2018. Tahıl ve tahıl ürünlerinin insan beslenmesi ve sağlık açısından önemi, Yozgat’ta tahılların durumu. 3rd International Bozok Symposium, May 03-05, Yozgat, Türkiye, pp: 1121-1130.

FAO. 2016. The agriculture sectors in the intended nationally determined contributions: Analysis, by Strohmaier R, Rioux J, Seggel A, Meybeck A, Bernoux M, Salvatore M, Miranda J and Agostini A. Environment and Natural Resources Management, Working Paper No. 62, Rome, Italy, pp: 92.

FAO. 2022. The state of agricultural commodity markets 2022. Food and Agriculture Organization. URL: https://openknowledge.fao.org/server/api/core/bitstreams/5b1d7bed-225a-444b-a041-c0844060a73c/content (accessed date: January 20, 2025).

French S. 2017. Revealed comparative advantage: What is it good for? J Int Econ, 106: 83-103.

Fukagawa NK, Ziska LH. 2019. Rice: Importance for global nutrition. J Nutrit Sci Vitaminol, 65(Supplement): S2-S3.

Geetha RS, Srivastava SK. 2018. Export of maize from India: Performance and determinants. Asian J Agri Extens Econ Sociol, 29(1): 1-11.

Govindasamy R, Bayramoğlu Z, Aziz S, Soysal U. 2023. Investigating the competitiveness of Pakistan agricultural products. Eurasian J Agri Econ, 3(2): 39-57.

Granabetter D. 2016. Revealed comparative advantage index: an analysis of export trade in the Austrian district of Burgenland. Rev Innov Competitiv, 2(2): 97-114.

Gutiérrez-Moya E, Adenso-Díaz B, Lozano S. 2021. Analysis and vulnerability of the international wheat trade network. Food Secur, 13: 113-128.

Hasan MR, Das D. 2024. What makes the second-largest apparel-exporting nation? An in-depth analysis of competitiveness and comparative advantage in Bangladesh’s apparel industry. Competitiveness Review: An Int Busin J. https://doi.org/10.1108/CR-01-2024-0011

Hinloopen J, Van Marrewijk C. 2001. On the empirical distribution of the Balassa Index. Weltwirtschaftliches Archiv, 137(1): 1-35.

Jagadeesh MS, Jahnavi AP, Vinay HT, Abhishek GJ, Abhishek SS, Chikkalaki AS. 2024. Export competitiveness of Indian coffee: analysing trade potential in the global market. J Scient Res Rep, 30(9): 51-61.

Jambor A, Babu S. 2017. Competitiveness of global agriculture: Policy lessons for food security. International Food Policy Research Institute. URL: https://cgspace.cgiar.org/server/api/core/bitstreams/f6ef1522-be64-464f-8879-8391b815bcab/content (accessed date: January 18, 2025).

Ji G, Zhong H, Nzudie HLF, Wang P, Tian P. 2024. The structure, dynamics, and vulnerability of the global food trade network. J Cleaner Product, 434: 140439.

Kutkowska B, Szuk T. 2020. Competitiveness on the global cereal market. Ann Polish Assoc Agri Agribusin Econ, 22(2): 142-152.

Maqbool MS, Mahmood T, Hussain S, Ashraf M. 2020. Analysis of trade competitiveness of Pakistan cereal products in global perspective. Rev Econ Devel Stud, 6(1): 97-106.

Marković M, Krstić B, Rađenović Ž. 2019. Export competitiveness of the Serbian agri-food sector on the EU market. Економика пољопривреде, 66(4): 941-953.

Marković M. 2019. Analysis of comparative advantages of Serbian exports at the sectoral level. Ekonomika, 65(3): 55-64.

Mikic M. 2005. Commonly used trade indicators: a note. ARTNeT capacity building workshop on trade research. URL: https://repository.unescap.org/handle/20.500.12870/4195 (accessed date: January 10, 2025).

Nithyashree ML, Ganapati M, Balasubramanian M, Gadag RN. 2020. Export performance and prospectus of maize (Zea mays L.) in India. Maize J, 9(2): 125-130.

Oktan G. 2024. Türkiye’nin hububat ürünlerindeki rekabet gücünün G7 ülkeleri ile karşılaştırılması. Yüksek lisans Tezi, Recep Tayyip Erdoğan Üniversitesi, Lisansüstü Eğitim Enstitüsü, Rize, Türkiye, pp: 84.

Pascucci F. 2018. The export competitiveness of Italian coffee roasting industry. British Food J, 120(7): 1529-1546.

Ranum P, Peña-Rosas, JP, Garcia-Casal MN. 2014. Global maize production, utilization, and consumption. Ann New York Acad Sci, 1312(1): 105-112.

Reed T. 2024. Export-led industrial policy for developing countries: Is there a way to pick winners? J Econ Perspect, 38(4): 3-26.

Rodríguez ML, Guaita PI, Marques PI. 2024. Competitiveness in theagricultural sector: a literature review. Clío América, 18(35): 52-69.

Saboniene A. 2009. Lithuanian export competitiveness: Comparison with other Baltic States. Eng Econ, 62(2): 49-57.

Şahin D. 2016. Tarımsal gıda ürünlerinde karşılaştırmalı üstünlüğün ölçümü: Türkiye örneği. Uluslar Sos Araş Derg, 9(43): 2177-2184.

Sarıçoban K, Kösekahyaoğlu L, Erkan B. 2017. Türkiye’nin tekstil ihracatındaki rekabet gücü düzeyinin belirlenmesi: 1996-2015 dönemi için bir analiz. Kesit Akad Derg, 8: 186-203.

Sarıçoban K, Kösekahyaoğlu L. 2016. Türkiye’nin tarimsal ürünlerdeki ihracat rekabet gücünün ölçülmesi: 1996-2015 dönemi üzerine bir analiz. ASSAM Uluslar Hakemli Der, 4(7): 78-96.

Sarıçoban K, Kösekahyaoğlu L. 2017. Ticaret sonrası verilerle rekabet gücünün ölçülmesinde kullanılan indeksler üzerine bir literatür taraması. Akad Sos Araş Derg, 47(47): 424-444.

Sing V. 2022. Three crops rule the world: Over-dependence on wheat, maizeand rice threatens the future of wildlife survival and global food security. State of India’s Environment – 2022: A Down to Earth Annual. Centre for Science and Environment, New Delhi, India, pp: 241-241.

Sovcovici V, Lopotenco V, Staver, L. 2024. Competitiveness of Moldovan agri-food exports at the regional level in the context of current crises. Scient Papers Ser Manag Econ Eng

Agri Rural Devel, 24(2): 865-874.
Statistics How To. 2025. Trimmed Mean / Truncated Mean: Definition, Examples. URL: https://www.statisticshowto.com/trimmed-mean/ (accessed date: January 28, 2025).
Thomé KM, Paiva VAL, Gois TCD. 2023. Wine international market structure and competitiveness. Int J Wine Busin Res, 35(4): 561-579.
Thomé KM, Paiva VAL. 2020. Sparkling wine international market structure and competitiveness. Wine Econ Policy, 9(2): 37-47.
Trade Map. 2023. Trade statistics for international business development. URL: https://www.trademap.org/Product_SelCountry_TS.aspx?nvpm=1%7c792%7c%7c%7c%7c10%7c%7c%7c4%7c1%7c1%7c2%7c2%7c1%7c1%7c1%7c1%7c1 (accessed date: January 16, 2025).
Umair Riaz U, Samreen T, Ijaz F, Rashid S, Hussain S, Ahmed Z, Malik HA, Zulqernain M, Mehdi SM. 2020. Rice production: Knowledge and practices for ensuring food security. Austin Publishing Group, Punjab, Pakistan, pp: 128.
United Nations Conference on Trade and Development. 2025. Data Hub: Empowering development through data and statistics. URL: https://unctadstat.unctad.org/datacentre/reportInfo/US.RCA accessed date: January 19, 2025).
Vollrath TL. 1991. A theoretical evaluation of alternative trade intensity measures of revealed comparative advantage. Weltwirtschaftliches Archiv, 127(2): 265-280.
World Bank. 2024. Indicators. URL: https://databank.worldbank.org/source/world-development-indicators# (accessed date: January 17, 2025).