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Evaluation of Pesticide Use in Greenhouse Tomato Production in the Context of Sustainability, Food Safety and Export Residue Notifications

Merve Mürüvvet Dag[a*], Hasan Yilmaz[a]

[a]*Department of Agricultural Economics, Faculty of Agriculture, Isparta Applied Sciences University, Isparta, TÜRKİYE*

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Corresponding Author: Merve Mürüvvet Dag, E-mail: mervedag@isparta.edu.tr
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ABSTRACT
The sustainability of agricultural production and access to healthy food are important issues in the agricultural sector. From a food safety perspective, pesticide residue problems are becoming an increasing concern for consumers worldwide. This study aims to evaluate pesticide use in greenhouse tomato production in terms of sustainability, food safety and export residue notifications. In this research, original data obtained from a face-to-face survey conducted with 115 greenhouse tomato farmers in Kumluca district of Antalya province was used. It was found that farmers on the surveyed farms used pesticides containing 57 different active ingredients. Various types of pesticides were used, including 12.9 kg/ha of insecticides, 10.9 kg/ha of nematicides, 8.8 kg/ha of fungicides, and 3.8 kg/ha of acaricides, resulting in a total of 36.5 kg/ha of pesticide use. The study revealed that 55.88% of the pesticides used by farmers were classified as hazardous according to the World Health Organization's (WHO) classification. The increasing number of pesticide residue notifications from European Union countries in recent years serves as a warning for Turkish farmers. Therefore, Türkiye needs to make more efforts to comply with international standards for the sustainability of tomato production and exports. As a result, in the research area, more efforts should be made to increase farmer training activities, tighten controls in greenhouse production, and strengthen safe food control mechanisms in order to reduce the use of pesticides for sustainable agriculture and safe food. In addition, greenhouse production support policies should be redesigned to encourage farmers to use biological control methods.

Keywords: Tomato, Pesticide, Türkiye, Residue, Sustainable agriculture

1. Introduction

The agricultural sector is an important sector that contributes to the country's economy and plays a role in people's nutrition. Therefore, ensuring both sustainability in agricultural products and access to healthy food appear to be very important issues. In recent years, there has been an increasing demand not only for producing larger quantities but also for the development of sustainable agriculture, where production is environmentally friendly, socially fair, and economically beneficial. It has been emphasized that agricultural food production practices should be improved for all types (conventional, integrated, organic agriculture, etc.) of agriculture (Wezel et al. 2014).

After potato, tomato is the second most important vegetable produced worldwide (Pishgar-Komleh et al. 2017; FAO 2023). According to Maham et al. (2020), tomato is among the most widely produced vegetables globally. Tomato production not only provides income for many rural families but also serves as a significant source of employment (Çetin & Vardar 2008). In 2021, the total tomato production area worldwide was determined to be 5 167 388 hectares (ha). The countries with the highest share of global tomato production are China (22.15%), India (16.35%), Nigeria (16.35%), Türkiye (3.20%), and Egypt (2.90%). These countries account for 60.95% of the world's tomato production area (FAO 2023). In Türkiye, tomato is primarily produced in the Antalya province, covering 62.10% of the total production (TÜİK 2023).

Türkiye's top tomato export destinations are determined as follows: Syria (18.58%), Ukraine (13.23%), Romania (10.78%), Bulgaria (9.15%), and Israel (8.90%) (TRADE MAP 2022). Russia was the largest importer of tomato in 2019; however, tomato exports to Russia have gradually decreased since then. Sezgin (2022) expresses the expectation that Türkiye's tomato exports to these countries will diminish due to the conflict between Russia and Ukraine.

In a report published by the Ministry of Trade in 2021 within the framework of European Union harmonization laws in Türkiye, it was emphasized that due to Türkiye being among the countries most affected by climate change, ensuring sustainability in agriculture and the importance of the Green Deal Action Plan for uninterrupted agricultural trade with the EU have been highlighted (Republic of Türkiye Ministry of Trade 2021). The Green Deal is a comprehensive policy framework by the European Union with the goal of becoming climate neutral by 2050. This action plan includes the target of climate neutrality by 2050, the widespread use of renewable energy sources, making industrial processes sustainable, promoting electric vehicles and clean fuels, reducing the use of pesticides and fertilizers, adopting sustainable farming practices, protecting ecosystems and biodiversity, and improving waste management (Szpilko & Ejdys 2022). In accordance with this target, efforts are being made to reduce pesticide and chemical fertilizer usage and to promote the widespread adoption of biological and biotechnical control methods. Regulations supporting certain sustainable agricultural practices indirectly encourage the reduction or proper and effective usage of pesticides.

Support for greenhouse production is promoted worldwide due to reasons such as countries' desire to ensure food security and food safety. However, the increasing use of intensive chemical inputs in greenhouse agriculture, reaching threatening levels for the environment and human health, and the growing concerns regarding the environment, food security, and human health have prompted governments to take certain measures (Yılmaz & Tanç 2019). Technologies used in greenhouse production and environmentally friendly agricultural practices are particularly supported by governments in developed countries (European Commission 2024). In developed countries, food security is considered part of preventive health policy and is given special importance (Wilson 1989). In Türkiye, the area and quantity of greenhouse production are constantly increasing. Supported by reasons such as providing significant agricultural export income for Türkiye, contributing to food security, and numerous farmers engaging in greenhouse production, greenhouse agriculture is encouraged to increase technology usage levels and implement environmentally friendly practices. Greenhouse agriculture in Türkiye is given special importance, especially due to greenhouse products being significant export commodities and food security issues, and various support policies are implemented by the government for different purposes using different tools (Anonymous 2024).

One of the significant food safety issues in agricultural production is pesticide residue problems in products. The purpose of pesticide use is to control and prevent plant pests and diseases. Improper use of pesticides in agricultural production, not adhering to the recommended dosage and techniques, leads to various adverse effects. Among these adverse effects are environmental pollution, health problems, and a decrease in soil and water quality. Furthermore, during pesticide application, certain pesticides may drift beyond the intended area of use, potentially causing harm to soil, water, and wildlife. There are many studies showing a positive relationship between pesticides and various diseases, such as leukemia, pancreatic cancer, breast cancer, etc., and their negative effects on the environment (Infante-Rivard et al. 1999; Alguacil et al. 2000; Dolapsakis et al. 2001; Bassil et al. 2007; Geiger et al. 2010; Kumar et al. 2012; Yılmaz, 2015a; Yılmaz 2015b; Mahmood et al. 2016; Sharma et al. 2019; Wang et al. 2024). These negative effects have prompted some countries to reduce pesticide use (Van Driesche & Bellows 2012).

It has been observed that there has been a certain increase in pesticide usage worldwide from the past to the present. Since 1990, there has been a 50.83% increase in pesticide usage globally. In Türkiye, this increase rate is 114.81%. Despite the relatively high increase in pesticide usage in Türkiye compared to 1990, it is observed that pesticide usage is lower than in developed countries. Pesticide usage per unit area was reported as 1.81 kg/ha globally and 3.18 kg/ha in the European Union in 2020. In Türkiye, the amount of pesticide usage per unit area is 2.32 kg/ha (FAOSTAT 2020).

Eyhorn et al. (2015) stated that with current knowledge, technology, and alternative production systems, pesticide usage can be reduced without compromising yield or increasing production costs. Additionally, they noted that various alternative methods for reducing pesticide usage are being developed worldwide. Among these methods are biological and biotechnical control, integrated pest management, the use of natural enemies, and sustainable farming techniques. In this context, it is important to first identify some information regarding farmers' pesticide usage. The study aims to determine the diseases and pests encountered by greenhouse tomato farmers, identify the types and amounts of pesticides used in tomato production, evaluate them in terms of sustainability, food safety and export residue notifications. Additionally, the hazard classes of pesticide types used in tomato production will be determined according to the classification of the World Health Organization (WHO), and the pesticide residue notifications made by the countries to which Türkiye exports the most tomatoes were also determined.

2. Material and Methods

The primary data for the study were obtained through face-to-face surveys conducted with greenhouse tomato farmers in the Kumluca district of Antalya province, Türkiye. Antalya province, which holds a significant position in tomato production in Türkiye (62.10%), was selected, and within it, Kumluca district, known for its intensive tomato production (16.30%), was chosen to represent the province. According to the data obtained from the Agriculture and Forestry District Directorate, there are 6 213 farmers engaged in greenhouse tomato cultivation in Kumluca district. A proportional approach was used to determine the sample size to best represent the target population. The number of farmers to be surveyed was calculated using the "proportional sampling" method (Miran 2010). The following formula was used to determine the sample size (Equation 1). As a result of the calculations, a total of 115 surveys were conducted in twenty-one villages, with a 95% confidence interval and an 8% rate of error. Consultations were held with personnel from the District Agriculture and Forestry Directorate to conduct the survey in settlements that would represent the greenhouse production activities and socio-economic aspects of Kumluca district. The greenhouse farms surveyed were selected randomly.

$$\mathbf{n} = \frac{\mathbf{Np(1-p)}}{\mathbf{(N-1)\sigma^2 + p(1-p)}} \qquad (1)$$

In the formula:
n = Sample Size,
N = Population Size (6213),
p= Estimation Rate (0.05 for maximum sample size),
$\boldsymbol{\sigma^2}$= Population Variance.

Descriptive statistics (N, %, x̄, σ) were used in the analysis of the data. Additionally, one of the significant aims of the study was to classify the types of pesticides used in tomato production according to the toxicity classification of the WHO. The active ingredients of these pesticides and the licensing status of the drugs used in tomato production by the Republic of Türkiye Ministry of Agriculture and Forestry were also determined. Subsequently, an independent two-sample t-test was conducted to determine if there was a significant difference between the quantity of product loss in tomato production and the specific diseases and pests encountered by farmers. Before conducting the t-test, it was checked whether the data were normally distributed and whether the variances of the groups were homogeneous; after performing the necessary checks, the t-test was applied.

3. Results and Discussions

The socio-demographic characteristics measured in research are important parameters in interpreting producers' decisions. Table 1 provides the socio-demographic characteristics of the farmers. Accordingly, the average age of the farmers was found to be 49.6 years. It was determined that 87.83% of the farmers have social security. The average level of education for the farmers was determined to be 8 years. Additionally, it was found that 54.78% of the farmers have non-agricultural income (Table 1). According to an OECD report, in Türkiye, 58% of individuals aged 25–64 have completed primary education, 20% have completed secondary education, and 22% have completed higher education (OECD 2022). According to the United Nations Development Program's Human Development Report, the average level of education in the world and Türkiye in 2021 was reported as 8.6 years (UNDP 2022). The results of the study indicate that the level of education is consistent with both the world average and the average in Türkiye. Yılmaz (2014) determined the average age of farmers in greenhouse tomato production using bumblebees as 44.02 years, while it was 48.32 years in farms not using bumblebees. Additionally, the education level of farmers in farms using bumblebees was found to be 7.59 years, compared to 6.86 years in farms not using bumblebees. In another study, the average age of farmers practicing in greenhouse vegetable production was found to be 40.45 years, with an average education level of 6.09 years (Engindeniz et al. 2010). Özkan et al. (2011) found that the average age of greenhouse tomato farmers was 42 years, the household size was 3.9 people, and 66.80% of the farmers were primary school graduates. In a study by Metin (2020), the average age of tomato farmers was found to be 42.27 years, with 38.13% having completed primary education and 20% having non-agricultural income. Another study conducted in the Kumluca district of Antalya, Türkiye, found that the average age of tomato farmers was 47.55 years, with an average education level of 6.44 years (Demircan et al. 2019). Sanga & Elia (2020) found that 96% of tomato farmers in Tanzania were aged 45 or younger, and 45% had completed secondary education. In another study, the average age of farmers was found to be 45 years, with 28% having completed secondary school or higher education (Ceylan et al. 2020). In another study, it was determined that 56.1% of farmers were aged between 41 and 60 years, 86.4% had a secondary education level or below, and 59.6% had non-agricultural income (Varoğlu 2022).

The agricultural production experience of the farmers was found to be 27.01 years, while their greenhouse production experience was found to be 25.1 years (Table 1). In another study, the average agricultural production experience of greenhouse tomato farmers was found to be 15.7 years (Özkan et al. 2011). In a study by Metin (2020), the average agricultural experience of tomato farmers was determined to be 22.49 years, while their greenhouse production experience was 19.11 years. Differences among farmers implementing biological and biotechnical control methods were identified in the study by Sayın et al. (2020). Accordingly, the average age of farmers implementing these control methods was 52.3 years, with an education level of 8.1 years and an agricultural experience of 28.3 years, whereas those not implementing these methods had an average age of 51.3 years, an education level of 8.4 years, and an agricultural experience of 25.5 years. It was found that 77.39% of the farmers were not members of any farmer organization (Table 1). In another study, it was determined that 93.77% of the farmers were registered with any farmer organization (Varoğlu 2022).

The average farm size was determined to be 1.01 ha, with an average greenhouse area of 0.71 ha (Table 1). Karaman & Yılmaz (2007) found that tomato farmers had an average farm width of 2.81 ha in their study. Çanakcı & Akıncı (2009) determined that the average greenhouse size of farms in another study involving greenhouse farmers was 0.14 ha. In another study focusing on tomato greenhouses, the average farm size was determined to be 0.46 ha (Özkan et al. 2011). In a study conducted in the Kumluca district of Antalya province, Demircan et al. (2019) found that the greenhouse width of farmers averaged 0.33 ha. In another study, the average farm width of tomato farmers was found to be 1.01 ha, with an average greenhouse width of 0.83 ha (Metin 2020). Yılmaz (2014) showed that the greenhouse size was 0.57 ha in farms where bumblebees were used, while it was determined to be 0.55 ha in farms where bumblebees were not used. In the study by Sayın et al. (2020), they revealed that farms using biological and biotechnical control methods (5.14 ha) had a higher average cultivated land area compared to farms not using them (4.19 ha).

Table 1 also includes some general information about tomato production by farmers in the Kumluca district of Antalya province, Türkiye. The average tomato production area on the surveyed farms was determined to be 0.50 ha, with an average greenhouse age of 17.07 years. The average yield in tomato production was found to be 152.5 tons per hectare. These yield values vary depending on the agricultural techniques applied by tomato farmers, the quality of seedlings used, growing conditions, and greenhouse conditions. The average price of tomato sold by farmers in Türkiye was determined to be $0.41/kg. The research recorded the lowest price at $0.21/kg and the highest price at $0.91/kg. Tomato prices fluctuate depending on seasonal factors, supply and demand balance, export pathways, production quantity, and quality. The product loss in tomato production is 9,175.9 kg/hectare. It was determined that product losses occurred in all of the examined farms due to the effects of diseases and pests, as well as the harvesting, storage and marketing processes. Özkan et al. (2011) specified the average usage period of plastic greenhouses used by tomato farmers in their studies. Accordingly, it was found that 49.13% had a usage period of 1–10 years, 45.95% had a usage period of 10–20 years, and 4.91% had a usage period of 20 years or more. In another study conducted in the Kumluca district of Antalya province, the average tomato yield was determined to be 158 tons/hectare (Demircan et al. 2019). In another study, the average tomato yield was found to be 108.8 tons/hectare on farms using bumblebees and 94.30 tons/hectare on farms not using bumblebees (Yılmaz 2014).

In the study, it was determined that 49.57% of the farmers implement biotechnical control. However, it was found that not all farmers adopt biological control methods (Table 1). These significant findings indicate that many farmers in the greenhouse tomato production prefer biotechnical control, yet not all farmers have adopted biological control methods. Studies conducted by Mason and Huber (2002), Topuz (2005), and Pérez-García et al. (2011) emphasize the importance of environmentally friendly biopesticides and biotechnical/biological control methods, highlighting the necessity for further research and implementation in this regard.

Table 1- Socio-demographic and technical characteristics of farmers and farms

Socio-Demographic Characteristics	***$\bar{x}$ / %***
Age (years) (std. deviation: 10.969)	49.6
Education level (years) (std. deviation: 8.0)	8.0
Percentage of those with social security (%)	87.83
Percentage of those with non-agricultural income (%)	54.78
Years of agricultural production experience (years) (std. deviation: 13.243)	27.01
Years of greenhouse production experience (years) (std. deviation: 12.061)	25.10
Membership in farmer organizations (%)	22.61
Technical Characteristics	***$\bar{x}$ / %***
Total farm area (ha) (std. deviation: 0.831)	1.01
Total greenhouse area (ha) (std. deviation: 0.669)	0.71
Age of greenhouse (years) (std. deviation: 9.531)	17.07
Tomato production area (ha) (std. deviation: 0.447)	0.50
Tomato yield (kg/ha) (std. deviation: 3.290)	152 456
Tomato selling price ($/kg) (std. deviation: 0.228)	0.41
Product loss (kg/ha) (std. deviation: 492.180)	9 175.90
The rate of farms experiencing product losses (%)	100.00
Percentage of those implementing biotechnical control (%)	49.57

Table 2 presents the purpose of tomato production and the countries to which tomato are exported from the Antalya province. According to the table, it was determined that 14.78% of the farmers produce solely for domestic consumption, 33.91% produce solely for export, and 51.31% produce for both domestic consumption and export purposes. When examining the countries to which tomato are exported from the Antalya province, it was found that the highest exports are to Russia (73.04%), Ukraine (39.13%), Romania (25.22%), and Bulgaria (16.52%). In 2022, among the top 10 countries to which Türkiye exported tomato, Syria (18.58%), Ukraine (13.23%), Romania (10.78%), Bulgaria (9.15%), Israel (8.90%), Russia (6.97%), Germany (4.52%), Poland (4.26%), Georgia (3.76%), and the Netherlands (2.95%) were identified (TRADE MAP 2022).

Table 2- Purpose of tomato production and exported countries

	N	*%*
Purpose of Tomato Production		
Domestic consumption	17	14.78
Export	39	33.91
Both	59	51.31
Exported Countries[1]		
Russia	84	73.04
Ukraine	45	39.13
Romania	29	25.22
Bulgaria	19	16.52
Czech Republic	3	2.61
Moldova	3	2.61
Germany	1	0.87
Georgia	1	0.87
Poland	1	0.87
Serbia	1	0.87

[1]: Multiple options have been selected.

Table 3 presents the most common diseases and pests encountered by farmers in greenhouse tomato production. It was determined that the most encountered pest in greenhouse tomato production, referred to as *Tuta absoluta*, accounted for 99.13%, while the most prevalent disease was *Leveillula tauric* (Powdery mildew in Solanaceae), accounting for 79.13%. Following *Tuta absoluta*, the next most encountered pests were *Tetranychus urticae* (Red spider mite) at 94.78%, *Bemisia tabaci* (Whitefly) at 89.57%, and *Helicoverpa armigera* (African bollworm) at 86.96%. After *Leveillula tauric*, the most common diseases encountered were *Phytophthora infestans* (Late blight) at 71.30% and *Botrytis cinerea* (Gray mold) at 59.13%.

Table 3- Diseases and pests encountered by farmers in greenhouse tomato production[1]

Pests	***Number of Farmers (N)***	***%***
Tuta absoluta (Tomato leafminer)	114	99.13
Tetranychus urticae (Red spider mite)	109	94.78
Bemisia tabaci (Whitefly)	103	89.57
Helicoverpa armigera (Corn earworm)	100	86.96
Thysanoptera (Flower thrips)	12	10.43
Myzus persicae (Green peach aphid)	6	5.22
Diseases	***Number of Farmers (N)***	***%***
Leveillula tauric (Powdery mildew in Solanaceae)	91	79.13
Phytophthora infestans (Late blight)	82	71.30
Botrytis cinerea (Gray mold)	68	59.13
Fusarium oxysporum (Fusarium with in tomato)	23	20.00
Meloidogyne spp. (Root-knot nematodes)	18	15.65
Aculops lycopersici (Tomato russet mite)	7	6.09
Rhizoctonia solani (Root rot)	3	2.61
Alternaria solani (Early blight)	2	1.74

[1]: Multiple options were selected

Figure 1- *Phytophthora infestans* (Mildew)

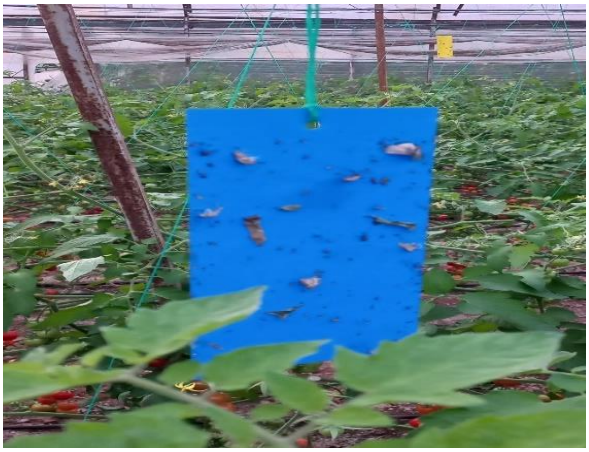

Figure 2- Biological control (Blue sticky trap)

Table 4 presents the relationship between specific diseases and pests encountered by tomato farmers and the amount of product loss in tomato production. The differences in the means of product loss due to the occurrence of diseases or pests in tomato were determined using an independent t-test. Accordingly, the average product loss was found to be 9,256 kg/ha in tomato affected by *Tuta absoluta* (Tomato leafminer), 9,345 kg/ha in tomato affected by *Tetranychus urticae* (Red spider mite), and 9,850 kg/ha in tomato affected by *Phytophthora infestans* (Late blight). The independent t-test results indicated that these differences were statistically significant. These findings demonstrate that the production quantity of tomato is affected by specific diseases or pests, leading to losses in tomato production.

Table 4- Product loss of tomato farmers according to diseases and pests encountered in the greenhouse

The amount of tomato product loss (kg/ha)		***N***	***Mean ±Std. Deviation***	***t-test***
Tuta absoluta (Tomato leafminer)	Present	114	9 256±486.692	-2.125*
	Absent	1	0.00±0	
Tetranychus urticae (Red spider mite)	Present	109	9 345±494.193	-2.125*
	Absent	6	6 091±356.858	
Phytophthora infestans (Late blight)	Present	82	9 850±488.454	-2.361**
	Absent	33	7 500±467.413	

*: 0.10 and **: 0.05 are significant at the level.

In greenhouse tomato production, the use of pesticides and their quantities have a significant impact on yield. Table 5 shows the amounts of insecticides, fungicides, nematicides, and acaricides used by farmers in tomato production.

In the examined farms, it was found that an average of 12.9 kg/ha of insecticide (35.5%), 10.9 kg/ha of nematicide (29.9%), 8.8 kg/ha of fungicide (24.1%), and 3.8 kg/ha of acaricide (10.4%) were used, total 36.5 kg/ha of pesticide. In a study conducted on tomato production in greenhouses in the Serik district of Antalya province, Türkiye, it was reported that farms certified with EurepGAP used a total of 12.2 kg/ha of pesticides, including 9.7 kg/ha of fungicide, 0.5 kg/ha of insecticide, and 2 kg/ha of nematicide. Conversely, farms without EurepGAP certification were found to use a total of 43.7 kg/ha of pesticides, including 34.1 kg/ha of fungicide, 2.3 kg/ha of insecticide, and 9.3 kg/ha of nematicide (Bayramoğlu et al. 2010). In another study conducted in Antalya province, it was reported that for winter tomato production in greenhouses, 14.8 kg/ha of pesticides were used, including 1.5 kg/ha of insecticide, 11.8 kg/ha of fungicide, and 1.3 kg/ha of nematicide. In the same study, for summer tomato production, 8.2 kg/ha of pesticides were used, including 1.6 kg/ha of insecticide, 5.9 kg/ha of fungicide, and 0.7 kg/ha of nematicide. Additionally, for spring tomato production, 4.3 kg/ha of pesticides were used, including 0.6 kg/ha of insecticide and 3.7 kg/ha of fungicide (Özkan et al. 2008). In a study conducted with tomato producers in Kenya, it was found that producers used insecticides (97.66%), fungicides (91.93%), and herbicides (16.67%) in excessive doses (Kinuthia, 2019). Comparing with other studies, it can be said that pesticide use in greenhouse tomato production varies according to cultivation techniques, cultivation periods, density of pests and diseases, whether farms have EurepGAP certification, and whether use biotechnical and biological control techniques. EurepGAP, represents an international standard used to certify that agricultural products are produced in a safe and sustainable manner (Kurek 2007). European Union countries and other advanced nations may require compliance with this standard for agricultural products. Having this certification can enhance the acceptability and reliability of products in international markets. However, this requirement may vary depending on the type of product, target markets, and buyers.

It has been revealed that farmers do not comply with the recommended pesticide doses from agricultural engineers and agricultural extension agents (Table 5). The reason for farmers not adhering to the recommended pesticide doses may be attributed to their lack of sufficient knowledge or awareness about proper usage practices. Increasing agricultural extension activities is considered a potential solution to prevent unconscious pesticide use, as it would provide guidance to farmers on proper usage. In their study, Ombeni et al. (2021) indicated that farmers' knowledge about pesticide use in tomato, their age, the number of their children, and the nutritional values of agricultural products produced with and without pesticides are influenced by product prices. Another study highlighted that intensive pesticide use prevails in greenhouse vegetable farming in Antalya province, and most farmers tend to excessively use pesticides without proper consideration (Özkan et al. 2022).

It was determined that 59.13% of the surveyed farms have regular communication with an agricultural consultant, while 40.87% do not have an agricultural consultant. Additionally, the frequency of visits by agricultural consultants was determined in the study, with 41.18% of farmers stating that consultants visit their greenhouse once a week, 32.35% every two weeks, 19.12% once a month, and 7.35% every ten days (Table 5).

In the study area, farmers mostly make decisions about pesticide use themselves (91.30%), but they also receive support from agricultural engineers, agricultural consultants, and technical staff (74.78%) regarding its use (Table 5). In a study conducted in the Kumluca district of Antalya province, Türkiye, it was stated that farmers mainly base their decisions on agricultural pesticide use on recommendations from pesticide dealers (61.7%) (Kan, 2002). In the research by Nguetti et al. (2018), 63.5% of farmers expressed that their own experience influences their decisions on pesticide use. Another study indicated that farmers determine the pesticides they use in vegetable production based on information obtained from agricultural pesticide dealers, elders in the family, and other farmers (Malgie et al. 2015).

Table 5- Pesticide usage and pesticide usage behaviour in surveyed farms

Type of agricultural chemicals	*Used amount (gr-ml-cc)/ha*	*%*
Insecticides	12 948.07	35.46
Nematicides	10 944.65	29.98
Fungicides	8 807.95	24.12
Acaricides	3 810.80	10.44
Total pesticides	36 511.47	100.00
	N	**%**
Do you have a regular agricultural consultant		
Yes	68	59.13
No	47	40.87
How often do agricultural consultant visit?		
Weekly	28	41.18
Every ten days	5	7.35
Biweekly	22	32.35
Monthly	13	19.12
Decision making on pesticide usage[1]		
Personal choice	105	91.30
Agricultural Engineer/Agricultural Consultant/Technical Staff	86	74.78
Family members	7	6.09
Other farmers	7	6.09

[1]: Multiple options were selected.

Due to the significant role of tomato exports, the agricultural chemicals used in the production process are crucial. Furthermore, examining this issue is of great importance in the context of sustainable agricultural production. In Table 6, the pesticides used by farmers are grouped according to the toxicity classification of the World Health Organization (WHO) for tomato production. It was determined that farmers on the surveyed farms used pesticides containing 57 different active ingredients.

Farmers commonly use insecticides, including Laser (60.00%), Radiant 120 SC (56.52%), Movento SC 100 (37.39%), Mospilan 20 SP (32.17%), Uphold 360 SC (20.87%), and Voliam Targo (19.13%). It has been determined that 55.88% of the pesticides used by farmers are classified as hazardous according to the World Health Organization's (WHO) classification. The most commonly used acaricides by farmers are Agrimec EC (33.91%), Actinmor (23.48%), Capella (19.13%), Bamilda (10.43%), and Ariphut (10.43%). Most of the acaricides used are classified as highly hazardous or fall into the low risk acute hazard category under normal use. Commonly used fungicides by farmers include Signum WG (34.78%), Dikotan M-45 (24.35%), Trimaton (20.00%), Nirmal (17.39%), and Collis SC (16.52%). The fungicides used generally fall into the WHO hazard classification categories of slightly hazardous, moderately hazardous, or low risk of acute hazard under normal use. It has been found that nematicides are used in low quantities by farmers, with Pagos 10 G (6.09%) and Tervigo 20 SC (4.35%) being the most commonly used. The nematicides used are generally classified as slightly hazardous or highly hazardous in toxicity.

It has been revealed that a significant amount of pesticides are used in greenhouse tomato production in the research area. It was determined that farmers not only use agricultural chemicals when diseases/pests occur but also for preventive purposes before diseases/pests appear. In a study conducted in Egypt, the average contents of HCB, lindane, dieldrin, heptachlor epoxide, and DDT derivatives in tomatoes were found to be 0.009 mg/kg, 0.003 mg/kg, 0.006 mg/kg, 0.008 mg/kg, and 0.083 mg/kg, respectively. Additionally, the levels of dimethoate, profenofos, and pirimiphos-methyl were determined to be 0.461 mg/kg, 0.206 mg/kg, and 0.114 mg/kg, respectively (Abou-Arab 1999). In the study by Nguetti et al. (2018), it was noted that 6% of farmers conducted post-harvest spraying to protect their crops. Kan's (2002) study revealed that 49.5% of farmers considered pre-emptive spraying necessary before the appearance of pests. Additionally, it was indicated that 63% of farmers who sprayed more than 22 times during a production season operated in plastic greenhouses. Engindeniz et al. (2010) found that farmers used 36% more pesticides for tomato grown in glass greenhouses. The reason for this was attributed to 43.3% of farmers believing that the recommended dosage was not effective enough and 36.7% stating that diseases and pests had developed resistance. In the study conducted by Hepsağ & Kızıldeniz (2021), it was found that in tomatoes grown in the Mediterranean region of Türkiye, 61.5% of the samples had detectable residues of one or more pesticides. The most commonly found residues included methyl chlorpyrifos, cyfluthrin, deltamethrin, and acetamiprid.

Table 6- The types of pesticides used in tomato production according to the WHO Hazard Classification

	Trade name	*Chemical family*	*Toxicity class[1]*	*Status[2]*	*Number of farmers (N)****	*%*
Insecticide	Laser	480 g/l Spinosad	III	Registered	69	60.00
	Radiant 120 SC	120 g/l Spinetoram	U	Registered	65	56.52
	Movento SC 100	100 g/l Spirotetramat	III	Registered	43	37.39
	Mospilan 20 SP	%20 Acetamiprid	II	Registered	37	32.17
	Uphold 360 SC	300 g/l Methozyfenozide + 60 g/l Spinetoram	U	Registered	24	20.87
	Voliam Targo	45 g/l Chlorantraniliprole + 18 g/l Abamectin	U + Ib	Registered	22	19.13
	Hektaş Zodiac	100 g/l Spirotetramat	III	Registered	5	4.35
	Imperator 25 EC	250 g/l Cypermethrin	II	Registered	4	3.48
	Breaker 240 SC	240 g/l Sulfoxaflor	II	Registered	9	7.83
	No-fly	%20 Acetamiprid	II	Registered	10	8.70
	Liberator 10 EC	100 g/l Pyriproxyfen	U	Registered	11	9.57
	Atercle	240 g/l Mataflumizone	U	Unregistered	13	11.30
	Dacron WP	32000 IU/mg Bacillus thuringiensis var kurstaki strain SA-11	III	Registered	9	7.83
	Zoomilda	Malathion	III	Unregistered	4	3.48
	Neemarin	%5 Emamectin benzoate	II	Registered	8	6.96
	Bethrin 2.5 EC	25 g/l Deltamethrin	II	Registered	12	10.43
	Circaden 200 SC	200 g/l Cyantraniliprole	U	Registered	15	13.04
	Evander	%5 Emamectin benzoate	II	Registered	6	5.22
	Modesta	350 g/l Imidacloprid	II	Unregistered	9	7.83
	Tunga	222 g/l Flubendiamide	III	Registered	17	14.78
	Spintor 240 SC	240 g/l Spinosad	III	Registered	13	11.30
	Benevia 100 OD	100 g/l Cyantraniliprole	U	Registered	6	5.22
	Plemax	240 g/l Indoxacarb + 80 g/l Novaluron	II + U	Registered	7	6.09
	Altacor 35 WG	%35 Chlorantraniliprole	U	Registered	11	9.57
	Klarbon M22	227 g/l Chlorpyrifos methyl	III	Registered	6	5.22
	Dicarzol 50 SP	%50 Formetanate hydrochloride	Ib	Registered	8	6.96
Acaricide	Agrimec EC	18 g/l Abamectin	Ib	Registered	39	33.91
	Actinmor	18 g/l Abamectin	Ib	Registered	27	23.48
	Capella	240 g/l Bifenazate	U	Registered	22	19.13
	Bamilda	Bifenazate	U	Unregistered	12	10.43
	Ariphut	Paraffin oil	Not listed	Unregistered	12	10.43
	Hebanon	Hesoythiatepo	Not listed	Unregistered	7	6.09
	Puzzle 20 WP	%20 Pyridaben	II	Registered	7	6.09
	Efdal Hekzarun 50 EC	50 g/l Hexythiazox	U	Registered	6	5.22
	Zrmilda	Abamectin-propois	Not listed	Unregistered	6	5.22
	Tripsol	22.5 g/l Acrinathrin + 12.6 g/l Abamectin	U + Ib	Registered	4	3.48

Table 6 (Continue)- The types of pesticides used in tomato production according to the WHO Hazard Classification

	Trade name	*Chemical family*	*Toxicity class[1]*	*Status[2]*	*Number of farmers (N)****	*%*
Fungicide	Signum WG	%26.7 Boscalid + %6.7 Pyraclostrobin	U	Registered	40	34.78
	Dikotan M-45	%80 Mancozeb[4]	U	Unregistered	28	24.35
	Trimaton	500 g/l Metam-sodium	II	Registered	23	20.00
	Nirmal	100 g/l Penconazole	III	Registered	20	17.39
	Collis SC	200 g/l Boscalid + 100 g/l Kresoxim-methyl	U + III	Registered	19	16.52
	Lusen SC 500	250 g/l Fluopyram + 250 g/l Trifloxystrobin	III + U	Registered	14	12.17
	Hektaş Aktor	500 g/l Imazalil	II	Registered	9	7.83
	Qualy 300 EC	300 g/l Cyprodinil	Not listed	Registered	10	8.70
	Ippon 500 SC	Iprodione	III	Registered	6	5.22
	Yoma	375 g/l Fluazinam + 150 g/l Azoxystrobin	U	Registered	8	6.96
	Switch 62.5 WG	%37.5 Cyprodinil + %25 Fludioxonil	U	Registered	4	3.48
	Orvego	300 g/l Ametoctradin + 225 g/l Dimethomorph	III	Registered	6	5.22
	Ridomil Gold MZ 68 WG	500 g/l Chloratholonil + 37.5 g Metalaxyl-M	II	Registered	8	6.96
	Mastercop	65.82 g/l Copper oxychloride Copper sulfate	II	Registered	3	2.61
	Adolax	%80 Mancozeb[4]	U	Unregistered	5	4.35
	Amaline	266.6 g/l Metallic copper equivalent basic copper sulfate + 40 g/l Zoxamide	II + U	Registered	5	4.35
	Bonko	500 g/l Chlorothalonil	U	Unregistered	9	7.83
	Korconil 500 SC	500 g/l Chlorothalonil	U	Unregistered	10	8.70
	Luna Tranquility SC 500	375 g/l Pyrimethanil + 152 g/l Fluopyram	III	Registered	10	8.70
	Equation Pro	%30 Cymoxanil + 22.5 Famoxadone	II + U	Registered	1	0.87
	Albacore	65.82 g/l Copper oxychloride Copper sulfate	II	Registered	1	0.87
	Quadris Maxx	200 g/l Azoxystrobin + 125 g/l Difenoconazole	U + II	Registered	4	3.48
	Topguard EQ	296 g/l Azoxystrobin + 218 g/l Flutriafol	U + II	Registered	6	5.22
	Embrelia 140 SC	100 g/l Isopyrazam + 40 g/l Difenoconazole	II	Registered	11	9.57
	Origam FS	75 g/l Azoxystrobin + 37.5 Metalaxyl-m + 12.5 g/l Fludioxonil	U + II + U	Registered	1	0.87
	Tennis 360 SL	360 g/l Hymexazol	III	Registered	2	1.74
	Top-Copp 5 E	51.4 g/l Copper salts of fatty and rosin acids equivalent to metallic copper	II	Registered	2	1.74
Nematicide	Pagos 10 G	%10 Fosthiazate	Not listed	Registered	7	6.09
	Tervigo 20 SC	20 g/l Abamectin	Ib	Registered	5	4.35
	Velum Prime SC 400	400 g/l Fluopyram	III	Registered	3	2.61
	Bioact DC 216	$4.7*10^{10}$ * 216 adet spor/l Purpureocillium lilacinus 251 (Paecilomyces lilacinus strain 251)	Not listed	Registered	2	1.74
	Nemacur 400 EC	400 g/l Fenamiphos	Ib	Registered	2	1.74

[1]Toxicity class (Ia = Extremely hazardous; Ib = Highly hazardous; II = Moderately hazardous; III = Slightly hazardous; U = Unlikely to cause acute hazard under normal use; FM = Fumigant, unclassified; O = Former pesticide, unclassified. WHO (World Health Organization), 2019. (Accessed: 09.06.2023); [2]Anonymous, 2023. (Erişim Tarihi: 09.06.2023); [3]Farmers have declared the use of multiple plant protection products for diseases/pests; [4]The use and sale of fungicides that active ingredient is Mancozeb is prohibited by the Ministry of Agriculture and Forestry. However, farmers who have fungicides containing the active ingredient Mancozeb are allowed to use them until 31.12.2023. During the survey process of this research, farmers were encountered who used fungicides with the active ingredient Mancozeb within the allowed period. As a matter of fact, it was determined that 24.35% of the producers used Dikotan M-45 with the active ingredient mancozeb and 4.35% used Adolax; [5]The registration status of pesticides is based on the information provided by the Ministry of Agriculture and Forestry at https://bku.tarimorman.gov.tr/.

The RASFF (Rapid Alert System for Food and Feed) reports on non-compliance issues detected in exports from RASSF Window countries to European Union countries. These RASFF notifications, classified as information exchange or border rejection, form an online database. To maintain a balance between transparency and the protection of commercial information, individual company names and identities are not disclosed. In exceptional cases where the protection of human health demands greater transparency, the Commission takes appropriate measures through regular communication channels. The Commission also informs third-country authorities about notifications concerning products produced, distributed, or sent from these countries. Table 7 provides some information regarding pesticide residue notifications related to tomato exports from European Union (EU) countries to Türkiye in the year 2023. These notifications reflect the seriousness of various countries regarding chemical substances in agricultural products and the measures taken. In 2023, a total of seven notifications were made to Turkey from EU countries concerning tomato products. All of these notifications are related to pesticide residues. Three of these notifications are from Romania, while the others are from Germany, Croatia, Italy, and Slovenia. Out of these residue notifications, 5 are considered to be notifications requiring attention, while 2 are in the form of border rejection notifications. Border rejection is a measure taken against food and feed shipments tested at the external borders of the European Union and found to pose health risks. During this process, notifications are sent to all EU border points to increase the effectiveness of controls and prevent rejected products from re-entering the EU through another border entry point. This helps to ensure that food safety and health standards are effectively maintained at the EU's external borders.

As a result of pesticide residue notifications to Türkiye, education should be provided to farmers and other stakeholders in the agricultural sector regarding the use of pesticides, and transition to biological/biotechnical control methods should be encouraged. Additionally, export controls to the EU from Türkiye should be strengthened and rigorously monitored. Türkiye should prioritize improving its customs and food inspection processes and ensuring compliance with EU standards.

Table 7- Pesticide residue notifications from the EU to Türkiye in tomato exports in 2023

Subject	*Date*	*Classification*	*Risk Decision*	*Notifying Country*	*Hazards*
Unauthorized substance chlorpyrifos-methyl and exceeding pesticide pirimiphos methyl	23.06.2023	Information notification for attention	Potentially serious	Romania	Chlorpyrifos-methyl unauthorised substance,pirimiphos-methyl
Unauthorized substance (chlorpyrifos-methyl, 0,048 mg/kg - ppm)	08.05.2023	Information notification for attention	Potentially serious	Romania	Chlorpyrifos-methyl
Exceeding LMA pesticid chlorpirifos	11.04.2023	Information notification for attention	Serious	Romania	Chlorpyrifos-methyl unauthorised substance
Chlorpirifos-methyl in frozen oven semi-dried tomato	13.02.2023	Border rejection notification	Potentially serious	Italy	Chlorpyrifos-methyl unauthorised substance
Chlorpyrifos	26.05.2023	Information notification for attention	Potentially serious	Slovenia	Chlorpyriphos-ethyl
Unauthorized substance (Chlorothalonil)	29.03.2023	Information notification for attention	Serious	Germany	Chlorothalonil
Chlorothalonil	23.03.2023	Border rejection notification	No risk	Croatia	Chlorothalonil

Source: RASFF Window 2023

4. Conclusions

Adopting sustainable methods for combating plant diseases and pests, aiming to preserve the sustainability of agriculture and ecosystem health, offers a more environmentally friendly approach compared to traditional agricultural practices. Within this context, environmentally friendly methods such as promoting natural enemies, preserving biological diversity, and prioritizing soil health are crucial for controlling plant diseases and pests.

While pesticides commonly used in traditional farming practices may be effective in controlling plant diseases and pests, their overuse can lead to negative effects such as the development of resistance in harmful organisms, soil, water, and air pollution, and adverse impacts on human health. Therefore, farmer awareness campaigns should be conducted regarding the use of sustainable approaches, and the adoption of these practices should be encouraged.

The socio-demographic characteristics of greenhouse tomato farmers in the Kumluca district of Antalya province, Türkiye, as well as the technical features of their farms, were examined in the study. It was found that the education levels of the farmers were relatively low, and the size of agricultural farms consisted mostly of small-scale farms. Nearly half of the farmers were found to lack regular agricultural extension activities. Additionally, it was determined that a high proportion of farmers (91.30%) made pesticide usage decisions based on their own knowledge and experience.

It has been determined that the most common pests encountered by tomato farmers in greenhouse tomato production are *Tuta absoluta*, *Tetranychus urticae*, *Bemisia tabaci*, and *Helicoverpa armigera*, while the most common diseases encountered are *Leveillula tauric*, *Phytophthora infestans*, and *Botrytis cinerea*. Accordingly, it has been observed that the presence of *Tuta absoluta* and *Tetranychus urticae* pests, along with *Phytophthora infestans* disease, contributes to increased product losses in tomato production.

It has been determined that the average pesticide usage in the examined farms is 36.5 g/ha. Within the relevant production period, it was found that pesticides in the insecticide (35.46%), fungicide (24.12%), and acaricide (10.44%) groups were heavily utilized. It was also observed that farmers generally do not adhere to the recommended pesticide usage doses provided by agricultural engineers and extension agents. Increasing agricultural extension activities and providing guidance to farmers on the proper use of pesticides would be a crucial step in reducing indiscriminate pesticide usage.

Tomato is among the most significant export products in Türkiye. The study results indicate that nearly all farmers focus on tomato production for export purposes. The countries most commonly exported to are typically Russia, Ukraine, Romania, and Bulgaria. The use of pesticides in exported products is of significant importance. It is expected that these products have no residues and comply with the standards of the importing country. In this context, the diseases and pests encountered by farmers have been identified, and the pesticides used in their control have been determined. It was found that farmers on the examined farms used 57 different active substances in pesticides. Most of the insecticides used by farmers fall into the category of slightly hazardous, moderately hazardous, or posing a low acute risk under WHO hazard classification; acaricides mostly fall into the category of highly hazardous or posing a low acute risk under normal use; fungicides generally fall into the category of slightly hazardous, moderately hazardous, or posing a low acute risk under WHO hazard classification; and nematicides generally fall into the category of slightly hazardous or highly hazardous toxicity. Excessive pesticide usage has been detected in tomato grown in greenhouses in the research area. Farmers not only use pesticides when diseases or pests emerge but also as a preventive measure before the onset of diseases or pests. This practice not only has negative environmental impacts but also leads to immunity and resistance against pesticides. To promote the adoption of environmentally friendly practices, it would be beneficial to organize regular training programs through agricultural engineers and experts to raise awareness among farmers about the correct use of pesticides and the identification of diseases and pests specific to tomato cultivation. To minimize these adverse effects and preserve environmental health, farmers should be incentivized to adopt these methods through agricultural support mechanisms. Steps taken in this direction could help farmers adopt a more sustainable and environmentally friendly approach to agricultural practices.

As a result, the risks posed by pesticide usage to the sustainability of Türkiye's tomato exports and production should not be overlooked. It was determined in the study that 55.88% of the pesticides used by farmers are classified as hazardous, according to the World Health Organization (WHO). The increasing number of pesticide residue notifications from European Union countries in 2023 serves as a warning for Turkish farmers. Therefore, more efforts need to be made towards compliance with international standards to ensure the continuity of Türkiye's tomato exports. In this context, inspections need to be tightened, more selective pesticide use should be encouraged, quality control mechanisms should be strengthened, and supports provided to farmers should be redesigned to encourage sustainable agriculture. It is important to increase inspections in greenhouses where tomato production is carried out and to develop training programs for farmers to ensure the production of products that are safe for the environment and human health. Taking these measures will result in Turkey's entry into export markets, strengthening Turkey's image in export markets and increasing export revenues.

In order for the recommendations to be realized and the goals of safe food in tomato production to be achieved, it is critical to ensure the continuity of the inspection, monitoring and support mechanism and to implement it decisively and to clearly demonstrate of political and administrative willpower.

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