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Comparison of Acceptance and Preference Between Rabbit Burgers and Other Lean Meat Burgers by Young Consumers

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ABSTRACT
Burgers are proposed as an ideal way to increase rabbit meat consumption among young people in a context where it is declining in several countries, mainly due to less familiarity with and appetite for rabbit meat and greater demand for easy-to-cook preparations. This study compared the acceptance and preference of commercial rabbit burgers with those of pork, chicken and turkey using an untrained panel of 45 young Spanish consumers (23.5 years; 55.6% male). A first trial evaluated on cooked burgers: a) acceptance of organoleptic characteristics and overall assessment, using a 9-point hedonic scale and b) order of preference of burgers (1st to 4th position). For this purpose, the panellists were presented with a dish with 2 × 5 cm blind-coded samples of each of the four burgers, randomly placed and to be tasted and evaluated from left to right. Overall acceptance and sensory attribute ratings differed between cooked burgers, except for texture (6.9 points for rabbit burger). Odour was rated better in the cooked rabbit (6.8 points) and turkey burgers, worst in the pork burger, and intermediate in the chicken burger. The colour, appearance, juiciness and overall acceptance of the cooked rabbit (6.5, 6.8, 6.9 and 7.1 points, respectively), pork and turkey burgers were rated better than the chicken burger. The flavour of the cooked rabbit (7.2 points) and turkey burgers was better accepted than that of pork and chicken burgers. The elasticity of the cooked rabbit (6.6 points) and pork burgers was rated better than that of the chicken, while that of the turkey burger was intermediate. The cooked turkey burger was preferred first, followed by the rabbit (second position; average order 2.27) and pork burgers, while the chicken burger was ranked last. A second trial evaluated on raw burgers: a) acceptance of colour and visual appearance and b) order of preference for burgers. For this purpose, the panellists were presented with a dish containing a 3 × 3 cm blind-coded raw sample of each of the four burgers, arranged in random order, to be visually evaluated in a clockwise direction. The colour of the raw turkey burger was rated best, the chicken burger was rated worst, and the rabbit and pork burgers were rated in between. Visual evaluation of appearance scored best for raw turkey, rabbit and pork burgers and worst for chicken burger. The visual appearance of the raw turkey burger was ranked first, followed by the rabbit and pork burgers, while the raw chicken burger was ranked last. In both trials, the gender of the consumer had no effect, and there was no interaction with the type of cooked burger. In conclusion, rabbit burgers were rated at the same level as pork and turkey burgers and better than chicken burgers, showing the potential to increase rabbit meat consumption among young people, which would benefit from promotion using this presentation format targeted at this specific audience.

Keywords: Rabbit, Pork, Chicken, Turkey, Meat, Processed products, Consumer behaviour, Burgers

1. Introduction

Rabbit meat consumption, a traditional part of the Mediterranean diet and in other areas of the world, has experienced a significant decrease in Spain and other European countries in recent decades (Petracci et al. 2018; Ministerio de Agricultura, Pesca y Alimentación 2021). Among other causes, several factors have contributed to this decline in consumption, such as changes in lifestyle and food consumption habits that lead to less time spent for cooking traditional and home-made dishes (Montero 2015), changes in work habits and in the family size and structure (Ministerio de Agricultura, Pesca y Alimentación 2006), as well as a lower preference for the organoleptic characteristics and a progressive loss of contact with rabbit meat among some consumers, especially young people and children (González-Redondo et al. 2010; Montero 2015; Escribá-Pérez et al. 2019). Thus, rabbit meat consumption has been mainly concentrated among traditional older consumers (Escriba-Perez et al. 2017). This is in line with the current general food trends, characterised by increased demand for ready-to-eat and ready-to-cook food products with convenience features, as well as for healthier meats in terms of their nutritional value (Siddiqui et al. 2023). In this regard, rabbit meat has excellent nutritional properties, characterised by its low fat and cholesterol content, which makes it suitable for a sustainable human diet (Hernández & Gondret 2006).

Faced with this situation, for almost three decades in Spain, part of the processing industry's proposals to attract consumers to rabbit meat has consisted of market presentations alternatives to the whole carcass, such as cuts (half or quartered carcasses, thighs, loins, loin medallions, etc.) and processed products such as sausages and burgers (ASESCU 1996; De Santos 2019).

These formats and presentations simplify cooking, and some of them, such as sausages and burgers, are more attractive to younger consumers because they are familiar with their consumption when they are made with meat from other animal species that are more frequently consumed (Escribá-Perez et al. 2019). In Spain and other European countries, several companies market rabbit burgers (Fernández 2019; Priorelli 2019).

Some research has been published around the world on the effects of various ingredients, processing techniques, packaging and storage treatments on aspects such as shelf life, oxidative status, physicochemical properties, and microbiological quality of raw or cooked rabbit burgers (Tavares et al. 2007; Cossu et al. 2012; Dal Bosco et al. 2019; Mancini et al. 2015; Mancini et al. 2016; Mancini et al. 2017a; García-Vázquez et al. 2020; Mancini et al. 2020a; Mancini et al. 2020b; Silva et al. 2022; Śmiecińska et al. 2022), including their sensory evaluation (Tavares et al. 2007; Cossu et al. 2012; Mancini et al. 2017b; Mancini et al. 2020b; Silva et al. 2022; Śmiecińska et al. 2022). However, little research has been done on the acceptance and preference of commercial rabbit burgers by young consumers compared to burgers made with other meats that are more commonly available on the market.

In this context, this study aimed to evaluate the acceptance and preference of commercially available rabbit burgers, both raw and cooked, by a panel of young consumers by comparing them with burgers made with other lean meats such as pork, chicken and turkey. The main hypothesis is that young consumers, a segment of the population that is less inclined to consume rabbit meat, will accept commercial burgers made with rabbit meat well, to the same extent as those made with other more commonly consumed meats, because this presentation format, which also better meets the demand of this consumer segment for ready-to-cook food products, eliminates, masks or neutralises some of the characteristics and attributes that prevent them from consuming this meat, such as the bone content or the taste, which they are not familiar with.

2. Material and Methods

2.1. Consumer panel

In May 2021, a panel of 45 untrained young consumers was recruited from undergraduate, master's and doctoral students of the Higher Technical School of Agricultural Engineering at the University of Seville (Spain). The panellists were recruited through advertisements on the school's bulletin boards and social networks and participated voluntarily and with informed consent.

On average, the panellists were 23.5±0.38 years old (mean ± standard error), varying between 20 and 30 years with a mode of 23 years. Of the young consumers, 55.6% (*n*= 25) were men, and 44.4% (*n*= 20) were women.

2.2. Burgers

Commercial rabbit, pork, chicken and turkey burgers, purchased in hypermarkets in Seville, were evaluated. The burgers were packaged in a modified atmosphere in transparent pet-tray packages. The nutritional values and ingredients of the burgers are shown in Table 1. The burgers were kept refrigerated at 3 ºC until they were used in the sensory evaluation panel.

Table 1 - Nutritional facts (per 100 g of edible portion) and ingredients of the commercial burgers evaluated (information from the manufacturers labelling)

	Burger			
	Rabbit	***Pork***	***Chicken***	***Turkey***
Nutritional value				
Calories (kJ/kcal)	570/136	823/198	428/102	350/92
Fat (g)	6.0	14.9	3.4	1.5
Saturated fat (g)	2.6	5.7	1.1	0.5
Carbohydrates (g)	6.0	1.5	<1.0	0.9
Sugars (g)	0.5	<0.5	<0.5	0.0
Protein (g)	14.4	14.5	16.8	18.9
Salt (g)	1.85	2.74	2.15	1.33
Ingredients	Rabbit meat (75%), water, salt, natural spices, starch, vegetal fibres, pea protein, dextrose, preservative (sodium sulphite), antioxidant (ascorbic acid) and colour (carminic acid)	Pork meat (78%), water, rice flour, salt, emulsifier (monoglycerides and diglycerides of fatty acids), natural fermentation extracts, antioxidant (sodium ascorbate), spice extracts, potato starch and vegetal fibre, onion, white pepper, spices and vegetable extracts	Chicken meat (85%), water, rice flour, salt, emulsifier (monoglycerides and diglycerides of fatty acids), natural fermentation extracts, antioxidant (sodium ascorbate), spice extracts, potato starch and vegetal fibre, onion, white pepper, spices and vegetable extracts	Turkey meat (90%), water, antioxidants (sodium lactate, sodium ascorbate), salt, starch, natural aroma, spices, vegetable extract, garlic and parsley

2.3. Preparation and sensory evaluation of cooked burgers

The burgers were cooked on electric griddles (Jata® model GR2017, Tudela, Spain) using a little extra virgin olive oil to prevent sticking. The burgers were then served hot to the panellists 1 minute after cooking.

The colour differences between the burgers were measured by determining the physical coordinates of colour L* (lightness), a* (redness) and b* (yellowness) (Table 2) (CIE 1976) using a Minolta CM-700d (Konica Minolta® Co., Japan) spectrophotometer with illuminant D65 and a standard observer of 10°. For each burger sample, three determinations were made at different points approximately 1 minute after cooking.

Table 2 - Trichromatic coordinates characterising the colour of cooked rabbit, pork, chicken, and turkey burgers (n= 3; mean±standard error)

Trichromatic coordinates	*Burger*				*p-value*
	Rabbit	*Pork*	*Chicken*	*Turkey*	
L*	56.5 ± 0.76b	47.2 ± 3.01a	67.1 ± 1.41c	50.9 ± 2.89a	<0.001
a*	6.2 ± 0.45a	10.9 ± 1.19b	8.6 ± 0.80a	9.6 ± 1.53b	0.035
b*	12.7 ± 0.74a	18.7 ± 0.69c	17.9 ± 1.10b	21.2 ± 1.06c	<0.001

a–c: Means of the same trichromatic coordinate accompanied by different letters are different between cooked burgers (P<0.05)

The tasting sessions were carried out following standard methodologies for sensory evaluation with untrained consumers (Pagliarini 2002). The panellists were informed that they had to evaluate the burgers made of the four lean meats mentioned above, but the identification of the samples was blinded. The young consumers were provided with paper napkins, single-use cutlery sets, water and breadsticks. They were presented with a dish containing a 2 × 5 cm sample of each of the four burgers, blind-coded with three-digit random numbers, with the samples placed in random order for each panellist (Figure 1). They were instructed to taste and evaluate the burgers from left to right, and to eat breadsticks and drink water between each burger.

Figure 1 - Presentation of the cooked burger samples for tasting and evaluation by the panellists. From left to right: cooked chicken, pork, rabbit, and turkey burger samples

The panellists were first asked to rate the degree of acceptance of the organoleptic attributes (odour, colour, appearance, texture, flavour, juiciness and elasticity) and the overall acceptance for each type of burger using a 9-point hedonic scale (1= dislike extremely, 2= dislike very much, 3= dislike moderately, 4= dislike slightly, 5= neither like nor dislike, 6= like slightly, 7= like moderately, 8= like very much, 9= like extremely).

Secondly, using the same samples as for the previous evaluation, the young consumers were asked to rank them in order of preference, using a ranking scale of 1, 2, 3 and 4 for first, second, third and fourth preference, respectively.

The young consumers were also asked to indicate whether they could identify the type of meat used to make each burger.

2.4. Preparation and visual evaluation of raw burgers

Following the tasting and evaluation of the cooked burgers, in the same session, the panellists were asked to evaluate the visual appearance of the raw burgers in order to assess their attractiveness in a potential purchase decision. The raw burger samples were obtained from the same purchase lot as the cooked burger samples.

To this end, the young consumers were presented with a dish containing one 3 × 3 cm raw sample each of rabbit, pork, chicken and turkey burgers, blind-coded with a random letter and with the samples placed in random order for each panellist (Figure 2). The panellists were instructed to rate and evaluate the raw burgers in a clockwise direction.

For each raw burger sample, the panellists were first asked to rate their degree of acceptance of the visual appearance and colour of the burgers, using a 9-point hedonic scale (previously described).

Secondly, and on the same samples used for the previous evaluation, the young consumers were asked to rank them in order of preference by using the ranking scale of 1 to 4 for the preference in first to fourth position, respectively.

The colour differences between the raw burgers (Table 3) were evaluated using the same procedure and equipment as for the cooked burgers. For each raw burger sample, three determinations were made at different points approximately 1 minute after removing them from their packaging.

Table 3 - Trichromatic coordinates characterising the colour of raw rabbit, pork, chicken, and turkey burgers (n= 3; mean±standard error)

Trichromatic coordinates	*Burger*				*p-value*
	Rabbit	*Pork*	*Chicken*	*Turkey*	
L*	54.3 ± 1.59b	58.4 ± 1.24b	59.2 ± 1.90c	46.7 ± 1.51a	<0.001
a*	8.3 ± 0.39a	12.7 ± 0.56b	10.2 ± 0.97a	8.7 ± 0.89a	0.002
b*	11.0 ± 0.65a	15.0 ± 1.05b	9.6 ± 1.04a	10.2 ± 1.18a	0.005

a–c: Means of the same trichromatic coordinate accompanied by different letters are different between raw burgers (P<0.05)

2.5. Statistical analyses

For both cooked and raw burgers, differences in physical coordinates of colour between burgers were analysed by means of a one-way analysis of variance with burger type as a factor, followed by post-hoc Duncan's test to separate means.

Two generalised linear model (GLM) analyses were performed, with burger type and consumer gender as the factors, and the interaction between both factors was also assessed. The first was performed on the panellists' evaluation of the sensory attributes (odour, colour, appearance, texture, flavour, juiciness and elasticity) and overall acceptance of the cooked burgers, and the second was performed on the visual assessment of the colour and appearance of the raw burgers. Both GLM analyses were followed by the least significant difference post-hoc multiple comparison tests to identify differences in the ratings of sensory attributes and overall acceptance of the cooked burgers, as well as differences in the colour and appearance scores after visual assessment of the raw burgers. Two Friedman tests were carried out to analyse the preference ranking of the burgers; the first was performed on the cooked burgers and the second on the raw burgers. Both ranking analyses were followed by Nemenyi post-hoc multiple comparison tests to identify differences in burger rankings. Differences in the frequency of young consumers who correctly identified the type of meat in each cooked burger were analysed using contingency tables on which Pearson's χ^2 tests were performed.

For all comparisons, statistical significance was accepted at P<0.05. Quantitative results are presented as the mean and standard error. All statistical analyses were performed using the SPSS 15.0 statistical package (SPSS Inc. 2006).

3. Results and Discussion

To the best of our knowledge, this is the first study to investigate the acceptance and preference of rabbit meat burgers by a young consumer panel compared to burgers made with other lean meats. Indeed, there are previous works that have carried out sensory evaluations of rabbit meat burgers with trained assessors or consumer panels but without comparing them with burgers made with other types of meats and focusing on the effects of several ingredients (Mancini et al. 2017b; Mancini et al. 2020b; Silva et al. 2022; Śmiecińska et al. 2022), packaging or storage conditions (Cossu et al. 2012; Śmiecińska et al. 2022), or processing (Tavares et al. 2007) on aspects such as shelf life, oxidative status, physicochemical properties, and microbiological quality of raw or cooked rabbit burgers. Furthermore, this study was carried out using commercial burgers, while the literature reports investigations using burgers prepared *ad hoc* for the experiments. This means that practical implications for improving the marketing of processed rabbit meat products can be more easily derived from the present study than from most studies reported in the literature, which were carried out with experimental burgers instead of commercial ones. Another relevant aspect is that this study was conducted with young adult consumers, some of whom are emancipated and, as a whole, have the ability to buy and make purchase decisions for food products.

Table 4 shows the effects of burger type and consumer gender, as well as their interaction, on the assessment by young consumers of the sensory attributes of cooked rabbit, pork, chicken and turkey burgers. The burger type influenced (P<0.05) the assessment by young consumers of all sensory attributes and the overall assessment of the cooked burgers, except for texture

(P>0.05). The gender of the consumers did not influence this sensory assessment (P>0.05), nor was there any interaction between consumer gender and burger type (P>0.05). Table 5 shows the comparison of the acceptance of the sensory attributes, as well as the overall acceptance of the cooked pork, chicken and turkey burgers, evaluated by the young consumers.

In general terms, all the sensory attributes evaluated and the overall acceptance of the cooked burgers made with the four lean meats received medium-high average scores from the young consumers, varying between 5.6 and 7.4 out of 9 points. Odour was rated higher for the cooked turkey and rabbit burgers and lower for the pork burger, with the chicken burger being intermediate in acceptance between the rabbit and pork burgers. Colour, appearance and juiciness were equally accepted in the cooked rabbit, pork and turkey burgers, and worst valued in the chicken ones. The flavour of the cooked rabbit and turkey burgers was rated at a similar level and was better accepted than that of the pork and chicken burgers. The elasticity of the cooked rabbit and pork burgers was rated best at the same level, while it was rated worst in the chicken and at an intermediate level in the turkey. Texture showed a marginal tendency (P<0.1) to be better accepted for the cooked rabbit burger and the worst for the chicken burger, with turkey and pork burgers rated intermediate. Overall acceptance was similar for the cooked rabbit, pork, and turkey burgers and worst for the chicken burger.

Table 4 - Effects (p-value) of the factors Burger and Consumer gender on the assessment of odour, colour, appearance, texture, flavour, juiciness, elasticity, and overall assessment of cooked rabbit, pork, chicken, and turkey burgers (n= 45)

Factor	*Odour*	*Colour*	*Appearance*	*Texture*	*Flavour*	*Juiciness*	*Elasticity*	*Overall assessment*
Burger	0.035	<0.001	0.001	0.057	0.003	0.002	0.010	0.001
Consumer Gender	0.588	0.119	0.255	0.140	0.460	0.633	0.476	0.859
Burger × Consumer Gender	0.695	0.248	0.356	0.081	0.394	0.437	0.667	0.111

Table 5 - Comparison of acceptance (*) of sensory attributes of cooked rabbit, pork, chicken and turkey burgers by young consumers (n= 45; mean±standard error)

Sensory attribute	*Burger*			
	Rabbit	*Pork*	*Chicken*	*Turkey*
Odour	6.84 ± 0.22a,b	6.27 ± 0.21c	6.33 ± 0.19b,c	6.91 ± 0.18a
Colour	6.53 ± 0.20a	6.64 ± 0.20a	5.56 ± 0.22b	7.00 ± 0.20a
Appearance	6.82 ± 0.20a	6.78 ± 0.19a	5.91 ± 0.24b	7.02 ± 0.18a
Texture	6.87 ± 0.22	6.62 ± 0.22	6.04 ± 0.23	6.69 ± 0.22
Flavour	7.24 ± 0.17a	6.60 ± 0.28b	6.44 ± 0.21b	7.36 ± 0.17a
Juiciness	6.87 ± 0.23a	6.98 ± 0.24a	5.73 ± 0.28b	6.56 ± 0.24a
Elasticity	6.60 ± 0.23a	6.93 ± 0.22a	5.82 ± 0.23b	6.38 ± 0.23a,b
Overall assessment	7.07 ± 0.16a	6.82 ± 0.26a	6.13 ± 0.19b	7.16 ± 0.17a

*: Nine-point hedonic scale; 1 = dislike extremely, 2 = dislike very much, 3 = dislike moderately, 4 = dislike slightly, 5 = neither like nor dislike, 6 = like slightly, 7 = like moderately , 8 = like very much, 9 = like extremely. a–c: Means of the same attribute accompanied by different letters are different between cooked burgers (P<0.05)

The acceptance test based on an assessment of sensory attributes, in which the young consumers in this study participated, revealed that the cooked rabbit burger was rated favourably and, overall, at the same level as turkey and pork burgers and better than chicken burger. On the one hand, the young consumers gave high average scores, which varied between 6.53 and 7.24 out of 9 points, to all the sensory attributes and to the overall acceptance of the cooked rabbit burger (Table 5). On the other hand, the cooked rabbit burger was rated by the young consumers as follows: i) it was rated at the same level as the turkey burger (the highest scoring burger) for all sensory attributes and for overall acceptance; ii) it surpassed the pork burger in odour acceptance; iii) it was rated better than pork and chicken burgers in flavour acceptance; and iv) it surpassed the chicken burger in the acceptance of colour, appearance, juiciness and elasticity, as well as overall assessment (Table 5). With respect to colour assessment, Figure 1 shows that the cooked rabbit burger looked similar to the turkey and pork burgers and that the chicken burger had a paler colour. In fact, the trichromatic coordinates (Table 2) showed that the lightness (L*) of the cooked rabbit burger was intermediate between that of the chicken burger (which was the palest; Figure 1), on the one hand, and that of the turkey and pork burgers on the other. The redness (a*) of the cooked rabbit and chicken burgers was lower than that of the turkey and pork burgers, and the yellowness (b*) was lowest in the rabbit burger compared to the other cooked burgers. The different acceptance of the colour of the burgers by the young consumers was therefore due to the different colour of the meat used in them. In fact, colour is considered the most important attribute of meat quality perceived by consumers (Tomasevic et al. 2021). Indeed, even though they are all white or lean meats, there are differences in the colour of rabbit, pork, chicken and turkey meat (Tapp et al. 2011). Rabbit meat is considered one of the meats with the highest values of lightness and a relatively low saturation colour, and it resembles poultry meats, although its colour is deeper and brighter (Maj et al. 2012).

The fact that the young panellists did not indicate differences in texture between the cooked burgers prepared with the of the four different types of meat (Table 5) may be because the meat and the other ingredients are minced and mixed to give the burgers their typical shape and consistency (Tavares et al. 2007; Mancini et al. 2020a), thus acquiring a similar homogeneous texture. This fact can be considered favourable for the acceptance of rabbit meat by young consumers in this presentation format,

as it is known that the differences in texture between different meats influence consumers' acceptance of processed products (Lee et al. 2018). In fact, sensory evaluations reported in the literature have shown that the texture of frankfurters made from rabbit meat is similar to that of beef and superior to that of chicken meat (Whiting & Jenkins 1981). The texture of rabbit meat may therefore benefit from this presentation format.

Table 6 shows the ranking of overall preferences, based on organoleptic characteristics, expressed by consumers for cooked rabbit, pork, chicken, and turkey burgers, by consumer gender and together. The ranking test revealed that young consumers, considering both genders together, preferred the cooked turkey burger the first place, followed by the rabbit and pork burgers (with no difference between them), while the chicken burger was ranked last. When considering the gender of the consumer, men did not show significant differences between the cooked rabbit, turkey and pork burgers, while they ranked significantly lower for the chicken burger. Women, however, ranked the turkey burger first, with an average rank significantly higher than the chicken and pork burgers. Women ranked the cooked rabbit burger with no significant difference from the turkey and pork burgers.

Table 6 - Friedman test for ranking (*) of overall preference of cooked rabbit, pork, chicken, and turkey burgers by young consumers (mean range)

Gender	***Burger***				***p-value***
	Rabbit	***Pork***	***Chicken***	***Turkey***	
All panellists(*n*= 45)	2.27b (2^{nd})	2.29b (3^{rd})	3.27a (4^{th})	2.18b (1^{st})	<0.001
Men (*n*= 25)	2.36b	1.96b	3.32a	2.36b	0.002
Women (*n*= 20)	2.15bc	2.70ab	3.20a	1.95c	0.009

Ranking scale of 1, 2, 3, and 4 for preference in first, second, third, and fourth position, respectively. The ranking of the cooked burgers is indicated in parentheses. a–c: Values accompanied by different letters are different between cooked burgers (P<0.05)

The Friedman ranking test (Table 6) confirmed the panellists' preference for the cooked rabbit burger in second place after the turkey burger and also that the preference scores for the cooked turkey, rabbit and pork burgers were similar between them (P< 0.05) and significantly better than the chicken burger, ranked in last place. This reinforces the favourable acceptance of rabbit meat by young consumers under this presentation format.

Table 7 shows the frequency of young consumers who correctly identified the type of meat in the cooked burgers. The proportion of panellists who correctly identified the meat used to make the cooked burgers was low, showing no differences between burger types (P>0.05). Therefore, the presentation in the form of a burger also hinders young consumers' ability to identify the type of meat in each burger. Indeed, only between 13.3% and 28.9% of the panellists were able to correctly identify the type of meat in each cooked burger, with no difference between burger types (Table 7). This fact, which is partly due to the mincing of the meat and its mixture with spices and other ingredients during preparation (Tavares et al. 2007; Mancini et al. 2020a), may also favour the consumption of rabbit meat in this presentation format in the case of consumers who do not like the flavour and other organoleptic characteristics of rabbit meat under conventional presentations or cooked as traditional dishes. This circumstance that has already been reported, especially among young people (González-Redondo et al. 2010) and children (Escribá-Pérez et al. 2019).

Table 7 - Contingency table of young consumers that identified correctly the animal species of meat ingredient of cooked rabbit, pork, chicken, and turkey burgers (n= 45)

Meat ingredient identification	***Burger***				***p-value***
	Rabbit	***Pork***	***Chicken***	***Turkey***	
Correct identification, *n* (%)	10 (22.2)	12 (26.7)	13 (28.9)	6 (13.3)	0.304

Table 8 shows the effects of the factors of burger type and consumer gender, as well as their interaction, on young consumers' visual assessments of the colour and appearance of raw rabbit, pork, chicken and turkey burgers. Burger type influenced (P< 0.05) young consumers' visual assessment of the colour and appearance of the raw burgers. The gender of the consumer did not influence this visual assessment (P>0.05), nor was there any interaction between the gender of the consumer gender and burger type (P>0.05). Table 9 shows the comparison of the visual assessment of the colour and appearance of the raw rabbit, pork, chicken and turkey burgers evaluated by young consumers.

Table 8 - Effects (p-value) of the factors Burger and Consumer gender on the visual assessment of colour and appearance of raw rabbit, pork, chicken, and turkey burgers (n= 45)

Factor	***Colour***	***Appearance***
Burger	<0.001	<0.001
Consumer Gender	0.570	0.942
Burger × Consumer Gender	0.725	0.282

Table 9 - Comparison of visual evaluation of colour and appearance (*) of raw rabbit, pork, chicken and turkey burgers by young consumers (n= 45; mean±standard error)

Visual characteristic	*Burger*			
	Rabbit	*Pork*	*Chicken*	*Turkey*
Colour	7.00 ± 0,20b	6.89 ± 0.22b	4.80 ± 0.25c	7.64 ± 0.17a
Appearance	7.20 ± 0.17a	6.78 ± 0.21a	5.00 ± 0.23b	7.29 ± 0.20a

* Nine-point hedonic scale: 1 = dislike extremely, 2 = dislike very much, 3 = dislike moderately, 4 = dislike slightly, 5 = neither like nor dislike, 6 = like slightly, 7 = like moderately , 8 = like very much, 9 = like extremely. a–c: Means of the same visual characteristic accompanied by different letters are different between raw burgers (P<0.05)

In the young consumers' visual assessment, the colour and appearance of the raw burgers made from the four lean meats received medium to high average scores, ranging from 4.8 to 7.6 out of 9 points. The young consumers rated the colour of the raw turkey burger as the best and the chicken burger as the worst, with the rabbit and pork burgers scoring in the middle. Young consumers' visual evaluation of appearance scored best for the raw turkey, rabbit and pork burgers and worst for the chicken burger.

In this second part of this trial, the acceptance and preference of young consumers for the visual appearance of raw burgers, as these can be seen through the transparent packaging at the time of purchase, were evaluated. It was decided to carry out this evaluation based on the premise that the visual appearance of the raw burger may influence the purchase decision and subsequent consumption of the product. In fact, it is well known that the consumer's purchase decision depends on the appearance and colour quality of rabbit meat on meat shelves (Sanah et al. 2020). In this regard, the acceptance test based on the visual assessment of colour and appearance by the young consumers revealed differences between the raw burgers (Table 8) and a favourable evaluation of the rabbit burger (Table 9). Thus, the visual assessment of the appearance was rated higher for the raw turkey, rabbit and pork burgers (average scores ranging from 7.29 to 6.78 out of 9 points), while it was perceived as significantly worse (P<0.05) for the chicken burger (scoring only 5 points on average).

The panellists' visual assessment of colour also showed differences between the raw burgers (P<0.05), with the rabbit and pork burgers scoring well (7 out of 9 points) and being considered intermediate between the best-rated turkey burger, and the worst-rated chicken burger. This result is consistent with the differences in colour between the raw burgers that can be seen in Figure 2, where the colour of the raw rabbit and pork burgers seems similar, and the colour of the turkey and chicken burgers appears very different. In fact, the trichromatic coordinates (Table 3) were characterised by the fact that the lightness (L*) of the raw rabbit and pork burgers was intermediate between that of the chicken burger (which was the palest; Figure 2), on the one hand, and that of the turkey burger, which was the darkest, on the other hand. The redness (a*) and yellowness (b*) of the pork burger were higher than those of the other three raw burgers, which did not display differences among them for these two trichromatic coordinates. As previously discussed for the cooked burgers, the different acceptance of the colour of the raw burgers by the young consumers was due to the differences in the colour of the meat used as the main ingredient.

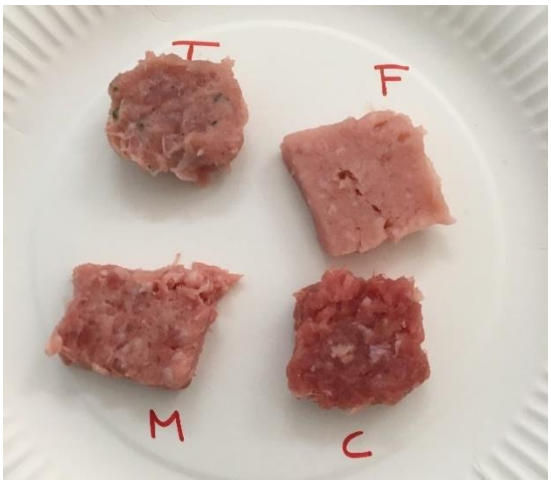

Figure 2 - Presentation of the raw burger samples for visual evaluation by the panellists. Raw chicken (F), pork (M), rabbit (T), and turkey (C) burger samples

Table 10 shows the ranking of overall preferences, based on visual appearance, expressed by consumers for raw rabbit, pork, chicken and turkey burgers, by consumer gender and together. The ranking test showed that young consumers, considering both genders together, preferred the visual appearance of the raw turkey burger first, followed by the raw rabbit and pork burgers (with no difference between them), while the raw chicken burger was ranked last. In general terms, this ranking pattern was maintained when analysing the gender of the panellists separately, with the only differences being that, on the one hand, men

ranked the raw pork burger as intermediate and no different from the raw turkey and rabbit burgers and, on the other hand, women ranked the raw rabbit burger as intermediate and no different from the raw turkey and pork burgers.

Table 10 - Friedman test for ranking (*) of overall preference of visual appearance of raw rabbit, pork, chicken, and turkey burgers by young consumers (mean range)

Gender	*Burger*				*p-value*
	Rabbit	*Pork*	*Chicken*	*Turkey*	
All panellists (*n*= 45)	2.29b (2nd)	2.29b (3rd)	3.69a (4th)	1.73c (1st)	<0.001
Men (*n*= 25)	2.44b	2.08bc	3.76a	1.72c	<0.001
Women (*n*= 20)	2.10bc	2.55b	3.60a	1.75c	<0.001

*: Ranking scale of 1, 2, 3, and 4 for preference in first, second, third, and fourth position, respectively. The ranking of the raw burgers is indicated in parentheses.a–c: Values accompanied by different letters are different between raw burgers (P<0.05)

The Friedman ranking test (Table 10) confirmed the preference of the young consumers for the raw rabbit burger in second place after the turkey burger and also that the preference scores of the raw rabbit and pork burgers were similar among them (P>0.05) and significantly higher than the chicken burger, which ranked in the last position. These findings confirm the favourable acceptance of rabbit meat by young consumers in this presentation format. This fact may favour the decision to purchase rabbit burgers when young consumers see them on the shelves of points of sale, as their raw appearance is well accepted compared to other types of meat burgers that are more common in the market.

Both in the sensory evaluation of the cooked burgers and in the visual evaluation of the raw burgers, the gender of the young consumers did not affect their acceptance and preference for rabbit meat burgers when compared to pork, chicken and turkey burgers. This is an interesting finding, because it is generally well known that women (Santos & Booth 1996; Kubberød et al. 2002a; Kubberød et al. 2002b; Kiefer et al. 2005), especially the youngest ones (Santos & Booth 1996; Kubberød et al. 2002a; Kubberød et al. 2002b), are less likely to eat meat than men, as has also been reported specifically for rabbit meat in several countries (Hui & McLean-Meyinsse 1996; McLean-Meyinsse 2000; González-Redondo et al. 2010). This phenomenon, which is more pronounced for red meat, is due to the fact that women tend to associate meat with unpleasant concepts, such as dead animals or blood, more frequently than men (Santos & Booth 1996). The presentation of rabbit meat in the form of a burger helps to avoid these associations and therefore makes it easier for women to make purchase and consumption decisions for rabbit meat, at least to the same extent as for burgers made with other types of meat.

The burger-shaped preparation and presentation also has some advantages over other commercial presentations of rabbit meat, which may contribute to its good acceptance, as confirmed in this trial. Among the main advantages, it is worth highlighting the absence of bones or the standardisation of flavour, thus eliminating or masking some characteristics of other presentations of this meat for which some young people and children under the age of 18 years claim not to consume (bone content, flavour, etc.; González-Redondo et al. 2010; Escribá-Pérez et al. 2019). Indeed, the production of rabbit burgers requires deboning (Petracci & Cavani 2013), and, on the other hand, the characteristic flavour of rabbit meat is modified by mixing it with other ingredients (Tavares et al. 2007), among which spices, salt, starch and vegetable fibres and extracts stand out (Table 1). The good performance of rabbit meat in the production of burgers was shown in a study on the inclusion of oat bran in rabbit burgers, which has reported even greater acceptability of the flavour, texture and overall quality of burgers with higher levels of rabbit meat and lower levels of oat bran (Silva et al. 2022).

The results of the present study, derived from the sensory evaluation of cooked burgers and of the visual assessment of raw burgers, show that this presentation format, in which the rabbit meat is deboned, minced, mixed with other ingredients and homogenised to achieve the typical shape, consistency and appearance of this product (Tavares et al. 2007; Petracci & Cavani 2013), makes it as attractive to young consumers as burgers from other more widespread white or lean meats with which they are familiar. The good evaluation and acceptance of rabbit burgers in this study are in line with what has been found in previous studies (Tavares et al. 2007; Mancini et al. 2017a; Silva et al. 2022). Furthermore, rabbit meat has excellent nutritional quality; it is healthy because it is lean and rich in protein with a high biological value, a low cholesterol content and a good lipid profile, as well as high phosphorus and low sodium content, among other nutritional properties favourable for the human diet (Hernández & Gondret 2006). Policy makers can use such characteristics of rabbit meat to propose it as a desirable, healthy diet component to be achieved at a population level for the general population or specific groups (EFSA Panel on Dietetic Products, Nutrition, and Allergies 2010) and also to propose using it to replace other types of meats high in nutrients of public health concern, such as saturated fat and sodium, in processed products such as burgers (Cocking et al. 2020).

One of the potential limitations of this study is that comparing commercially available burgers may have the drawback that rabbit, pork, turkey and chicken burgers differ in several factors, from the meat content to other ingredients such as the type and amount of seasoning, which may influence the choice. In this regard, it would be interesting for further research to compare the acceptance and preference of burgers made from rabbit meat with those made from other types of meat, using the same percentage of meat and other ingredients. Regardless, the meat content of the four commercial burgers evaluated in this study was high and relatively similar (range 75–90%; Table 1), so the type of meat in each burger essentially determined its evaluation.

At least in Spain, the marketing rabbit meat in processed formats alternative to the whole carcass, such as burgers, has been advocated for almost three decades (ASESCU 1996) as a way to increase the consumption of this meat among non-traditional consumer segments, young consumers, children and small family nuclei (Trocino & Xiccato 2000; Escribá-Pérez et al. 2019; Fernández 2019). In fact, several rabbit meat producers include rabbit burgers in their product portfolios. However, their presence at points of sale is sometimes irregular and often scarce because the distribution chains do not keep them on the shelves of hypermarkets and supermarkets due to their low turnover (Fernández 2019). Moreover, their price is higher than that of burgers made with other meats, in part due to the complexity of the deboning process, which is not automated as in the case of other types of meat (Petracci & Cavani 2013). These factors contribute to hindering the spread of their consumption, which could be increased with adequate promotion to make them known through promotional campaigns specifically aimed at young audiences (Fernández 2019). In fact, when segmenting Spanish consumers according to cooking styles at home, it has been proposed that rabbit burgers could fit well into the group of easy cooking styles, which includes the "ready to eat", “easy cooking” and “unconcerned” segments comprising a third of consumers (Montero et al. 2015), among which many young people are included.

4. Conclusions

Young consumers rated the colour, appearance, juiciness and elasticity of the cooked rabbit burger better than the chicken burger, its odour better than the pork burger, and its flavour better than the pork and chicken burgers. Overall, both in its raw and cooked form, rabbit burger is accepted at the same level as pork and turkey burgers and better than chicken burger, being the second most preferred burger by young consumers after visual assessment and sensory evaluation, with no difference between genders. These results reveal the potential of the burger presentation format to increase rabbit meat consumption among young people, which would benefit from promotion targeted at this specific audience.

Data availability: Data are available on request due to privacy or other restrictions.

Authorship Contributions: Concept: P.G.-R., Methodology: P.G.-R., E.L.-R., Investigation: P.G.-R., E.L.-R., Resources: P.G.-R., E.L.-R., Data curation: P.G.-R., E.L.-R., Writing: P.G.-R., E.L.-R. All authors have read and agreed to the published version of the manuscript.

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References

ASESCU (1996). Transformados cárnicos de conejo. *Boletín de Cunicultura* 83: 36-37

CIE. Commision International de l’Éclairage (1976). Official recommendations on uniform colour spaces. Colour difference equations and metric colour terms. Suppl 2. CIE Publication 15 Colourimetry, Paris.

Cocking C, Walton J, Kehoe L, Cashman K D & Flynn A (2020). The role of meat in the European diet: current state of knowledge on dietary recommendations, intakes and contribution to energy and nutrient intakes and status. *Nutrition Research Reviews* 33(2): 181-189. https://doi.org/10.1017/S0954422419000295

Cossu M E, Lamanna, M L, Picallo A B, Cumini M L, Gambetti P & Lazzari G (2012). Physical, chemical and sensory quality in rabbit burgers, refrigerated and stored under different conservation methods. In: Proceedings 10th World Rabbit Congress, 3-6, September Sharm El-Sheikh, Egypt pp. 887-890

Dal Bosco A, Mattioli S, Matics Z, Szendrő Z, Gerencsér Z, Mancinelli A C, Kovács M, Cullere M, Castellini C & Dalle Zotte A (2019). The antioxidant effectiveness of liquorice (*Glycyrrhiza glabra* L.) extract administered as dietary supplementation and/or as a burger additive in rabbit meat. *Meat Science* 158: 107921. doi.org/10.1016/j.meatsci.2019.107921

De Santos M L (2019). El sector de la carne de conejo se adapta a los cambios en el mercado. *Distribución y Consumo* 157: 48-51

EFSA Panel on Dietetic Products, Nutrition, and Allergies (NDA) (2010). Scientific Opinion on establishing Food-based Dietary Guidelines. *EFSA Journal* 8(3): 1460

Escriba-Perez C, Baviera-Puig A, Buitrago-Vera J & Montero-Vicente L (2017). Consumer profile analysis for different types of meat in Spain. *Meat Science*, 129: 120-126. doi.org/10.1016/j.meatsci.2017.02.015

Escribá-Pérez C, Baviera-Puig A, Montero-Vicente L & Buitrago-Vera J (2019). Children's consumption of rabbit meat. *World Rabbit Science*, 27: 113-122. doi.org/10.4995/wrs.2019.11991

Fernández M (2019). Nuevos cortes y elaborados, ¿cómo hacerlos más visibles? *Boletín de Cunicultura* 194: 6-8

García-Vázquez L M, Zepeda-Bastida A, Ayala-Martínez M & Soto-Simental S (2020). Infusion of *Chenopodium ambrosioides* consumed by rabbits: effects on carcass, meat and burger quality. *Food Science and Technology, Campinas*, 40(Suppl. 2), 451-457. doi.org/10.1590/fst.32819

González-Redondo P, Mena Y & Fernández-Cabanás V M (2010). Factors affecting rabbit meat consumption among Spanish university students. *Ecology of. Food and Nutrition* 49: 298-315. doi.org/10.1080/03670244.2010.491053

Hernández P & Gondret F (2006). Rabbit meat quality. In: L. Maertens & P. Coudert (Eds.), *Recent Advances in Rabbit Sciences*, Institute for Agricultural and Fisheries Research (ILVO), Melle, Belgium pp. 269-290

Hui J & McLean-Meyinsse P E (1996). Assessing the market potential for specialty meat: goat, rabbit, and quail. *Journal of International Food & Agribusiness Marketing*, 8: 55-68. doi.org/10.1300/J047v08n03_04

Kiefer I, Rathmanner T & Kunze M (2005). Eating and dieting differences in men and women. *The Journal of Men's Health & Gender*, 2: 194-201. doi.org/10.1016/j.jmhg.2005.04.010

Kubberød E, Ueland Ø, Rødbotten M, Westad F & Risvik E (2002a). Gender specific preferences and attitudes towards meat. *Food Quality and Preference*, 13: 285-294. doi.org/10.1016/S0950-3293(02)00041-1

Kubberød E, Ueland Ø, Tronstad Å & Risvik E (2002b). Attitudes towards meat and meat-eating among adolescents in Norway: A qualitative study. *Appetite*, 38: 53-62. doi.org/10.1006/appe.2002.0458

Lee N, Kwak H S, Joo J Y, Kang J & Lee Y (2018). Effects of partial replacement of pork meat with chicken or duck meat on the texture, flavor, and consumer acceptance of sausage. *Journal of Food Quality* 2018: 6972848. doi.org/10.1155/2018/6972848

Maj D, Bieniek J, Sternstein I, Węglarz A & Zapletal P (2012). Effect of genotype and sex on meat colour changes in rabbit. *Archiv für Tierzucht* 55(4): 385-390. doi.org/10.5194/aab-55-385-2012

Mancini S, Mattioli S, Nuvoloni R, Pedonese F, Dal Bosco A & Paci G (2020a). Effects of garlic powder and salt on meat quality and microbial loads of rabbit burgers. *Foods* 9(8): 1022. doi.org/10.3390/foods9081022

Mancini S, Mattioli S, Nuvoloni R, Pedonese F, Dal Bosco A & Paci G (2020a). Effects of garlic powder and salt additions on fatty acids profile, oxidative status, antioxidant potential and sensory properties of raw and cooked rabbit meat burgers. *Meat Science* 169: 108226. doi.org/10.1016/j.meatsci.2020.108226

Mancini S, Preziuso G & Paci G (2016). Effect of turmeric powder (*Curcuma longa* L.) and ascorbic acid on antioxidant capacity and oxidative status in rabbit burgers after cooking. *World Rabbit Science* 24: 121-127. doi.org/10.4995/wrs.2016.4207

Mancini S, Preziuso G, Dal Bosco A, Roscini V, Parisi G & Paci G (2017a). Modifications of fatty acids profile, lipid peroxidation and antioxidant capacity in raw and cooked rabbit burgers added with ginger. *Meat Science* 133: 151-158. doi.org/10.1016/j.meatsci.2017.07.003

Mancini S, Preziuso G, Dal Bosco A, Roscini V, Szendrő Z, Fratini F & Paci G (2015). Effect of turmeric powder (*Curcuma longa* L.) and ascorbic acid on physical characteristics and oxidative status of fresh and stored rabbit burgers. *Meat Science* 110: 93-100. doi.org/10.1016/j.meatsci.2015.07.005

Mancini S, Preziuso G, Fratini F, Torracca B, Nuvoloni R, Dal Bosco A & Paci G (2017b). Qualitative improvement of rabbit burgers using *Zingiber officinale* Roscoe powder. *World Rabbit Science* 25: 367-375. doi.org/10.4995/wrs.2017.7656

McLean-Meyinsse P E (2000). Assessing the market outlook for rabbit meat in Louisiana and Texas. *Journal of Food Distribution Research* 31: 139-144

Ministerio de Agricultura, Pesca y Alimentación (2006). La alimentación en España – 2006. Retrieved in May, 15, 2023 from https://www.mapa.gob.es/es/alimentacion/temas/consumo-tendencias/panel-de-consumo-alimentario/libro-la-alimentacion-en-espana-/libro2010-11-04_18.56.25.7562.aspx

Ministerio de Agricultura, Pesca y Alimentación (2021). Panel de consumo alimentario 2021. Retrieved in May, 12, 2023 from https://www.mapa.gob.es/es/alimentacion/temas/consumo-tendencias/panel-de-consumo-alimentario/

Montero L (2015). La cadena de valor del sector cunícola en España. Segmentación del consumo en base al Food-Related Lifestyle (FRL). Published PhD Thesis, Universidad Politécnica de Valencia, Valencia (Spain). RiuNet UPV Institutional Repository. https://riunet.upv.es/handle/10251/58775

Montero L, Escribá C & Buitrago J M (2015). El marketing como propuesta para incrementar el consumo de carne de conejo (III). *Boletín de Cunicultura* 174: 34-42

Pagliarini E (2002). Valutazione sensoriale. Aspetti teorici, pratici e metodologici. Ulrico Hoepli Editore, Milan, Italy.

Petracci M & Cavani C (2013). Rabbit meat processing: historical perspective to future directions. *World Rabbit Science*, 21: 217-226. doi.org/10.4995/wrs.2013.1329

Petracci M, Soglia F & Leroy F (2018). Rabbit meat in need of a hat-trick: From tradition to innovation (and back). *Meat Science*, 146: 93-100. doi.org/10.1016/j.meatsci.2018.08.003

Priorelli A (2019). Martini Alimentare, per un coniglio di Qualità. *Orizzonte* 14(2): 26-26

Sanah I, Becila S, Djeghim F & Boudjellal A (2020). Rabbit meat in the east of Algeria: motivation and obstacles to consumption. *World Rabbit Science*, 28(4): 221-237. doi.org/10.4995/wrs.2020.13419

Santos MLS & Booth DA (1996). Influences on meat avoidance among British students. *Appetite* 27: 197-205. doi.org/10.1006/appe.1996.0046

Siddiqui SA, Gerini F, Ikram A, Saeed F, Feng X & Chen Y (2023). Rabbit meat—production, consumption and consumers' attitudes and behavior. *Sustainability*, *15*(3): 2008. https://doi.org/10.3390/su15032008

Silva H L, Pires P G S, Lima A L S, Cristofolini A C, Netto D P, Miotto M, Verruck S, Hauptli L, Gouvêa F L & Moraes P O (2022). Hamburger de carne de coelho enriquecido com fibra de farelo de aveia: impacto nas propriedades físico-químicas e aceitabilidade. In: N.J.L. Rodriges (Ed.), *Ciência Animal e Veterinária: Inovações e Tendências*, 3rd ed., Editora Científica Digital, São Paulo, Brazil, Volume 3, pp. 125-136

Śmiecińska K, Gugołek A & Kowalska D (2022). Effects of garlic (*Allium sativum* L.) and ramsons (*Allium ursinum* L.) on lipid oxidation and the microbiological quality, physicochemical properties and sensory attributes of rabbit meat burgers. *Animals*, 12: 1905. doi.org/10.3390/ani12151905

SPSS Inc. (2006). *Manual del Usuario de SPSS Base 15.0*; SPSS Inc., Chicago, IL, USA.

Tapp W N, Yancey J W S & Apple J K (2011). How is the instrumental color of meat measured? *Meat Science* 89(1): 1-5. doi.org/10.1016/j.meatsci.2010.11.021

Tavares R S, Cruz A G, Oliveira T S, Braga A R, Reis F A, Hora I M C, Teixeira R C & Ferreira E F (2007). Processamento e aceitação sensorial do hambúrguer de coelho (*Oryctolagus cuniculus*). *Food Science and Technology* 27: 633-636. doi.org/10.1590/S0101-20612007000300031

Tomasevic I, Djekic I, Font-i-Furnols M, Terjung N & Lorenzo JM (2021). Recent advances in meat color research. *Current Opinion in Food Science* 41: 81-87. doi.org/10.1016/j.cofs.2021.02.012

Trocino A & Xiccato G (2000). La carne di coniglio: come variano le richieste del consumatore e la qualità del prodotto. *Eurocarni*, 8. Retrieved in July, 27, 2023 from https://www.pubblicitaitalia.com/carne/prodotti/eurocarni/2000/8/1420

Whiting R C & Jenkins R K (1981). Comparison of rabbit, beef, and chicken meats for functional properties and frankfurter processing. *Journal of Food Science*, 46(6): 1693-1696. doi.org/10.1111/j.1365-2621.1981.tb04465.x

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Determination of the Possibilities of Using Different Compost Materials as Seedling Growing Medias in Tomato, Cucumber and Pepper

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ABSTRACT
In the environmental context of Türkiye, the quantity of organic matter present in the soil is a crucial factor that affects its productivity potential. While peat offers an optimal growth condition, it is an expensive material due to its limited availability globally, and in Türkiye. Hence, the research employed compost, which could be a viable replacement for peat, and is a sustainable, and independent alternative resource. The study examined the effects of 13 diverse growing media, both in pure, and mixed form, which included a control treatment of a 2:1 peat to perlite mixture, and three composts derived from grape, apple, and tomato pulps. The research investigated various growth criteria, such as seedling height, hypocotyl length, and diameter, number of leaves per seedling, root length, seedling dry weight, and root dry weight of tomato, cucumber, and pepper plants. The study indicated that grape compost, apple compost, tomato compost:peat:perlite (GAT:P:P), and grape compost:peat:perlite (G:P:P) were viable alternatives to the traditional peat/perlite mixture for tomato seedlings. Similarly, grape compost (G), apple compost (A), and apple compost:perlite (A:P) showed potential as substitutes for cucumber seedlings while apple compost (A) proved a possible option for chilli seedlings. In particular, the treatments using solely apple or grape composts, or a combination of both, exhibited superior performance in comparison to the control treatment.

Keywords: Compost, Cucumber, Pepper, Seedling, Tomato

1. Introduction

Due to the quick global, and Türkiye population growth, there is an urgent need to increase plant production swiftly to match the growing food demand. Efficient utilization of organic waste, and by-products generated by fruit juice production, vegetable residues, and tomato paste factories is essential for sustainability purposes. These by-products can improve the use of fruits, and vegetables in plant production, and be integrated into agricultural practices.

In Türkiye, organic matter content is a crucial factor that affects soil productivity. The most significant source of organic matter in the country is barnyard manure (Bayındır et al. 2004). However, the unavailability of barnyard manure in the required quantity, timely availability, and adequate maturity levels prompt growers to explore alternative sources. This situation highlights the significance of utilising waste materials as a means of organic substance in agricultural regions (Özgüven et al. 1996). Organic matter deficiency in greenhouse soils can be remedied by employing materials like barnyard manure, peat, and compost (Tüzel et al. 1992; Tüzel 1996). Direct usage or composting of vegetable, and farm residues, barnyard manure, urban residues, industrial wastes, and akin materials left after harvesting can elevate soil organic matter levels (Entry et al. 1997; Pascual et al. 1997; Madejon et al. 2001; Bhattacharyya et al. 2003).

In recent years, utilising harvest wastes produced as a result of crop production, or various fabrication wastes whose raw materials are agricultural products (such as vegetable residues), as inputs in agricultural production has become a widely adopted practice for preventing environmental pollution, and waste. Consequently, leftover materials from agricultural production processing are repurposed in the same areas, thereby mitigating adverse environmental effects. Today, numerous studies have indicated that the majority of waste materials can be readily incorporated into soil to yield organic matter, and plant nutrients, or alternatively, can be used as growth media by blending them in specific ratios (Aydeniz & Brohi 1991; Özenç 2004; Benito et al. 2005; Benito et al. 2006).

Organic, inorganic, and synthetic growing media are utilised in soilless cultivation (Leonardi 2004; Gül 2008). The depletion of global, and Türkiye peat resources, declining perlite reserves, and waste concerns surrounding rock wool have stimulated

demand for readily available, cost-effective materials suitable for soilless agriculture from local sources (Frolking et al. 2001; Tüzel & Gül 2008). As a result, composts derived from vegetable, and fruit waste offer a practical solution that could considerably curtail both input costs, and reliance on foreign imports for commercial soilless agriculture, and seedling cultivation.

In this study, the possibilities of using compost materials prepared from tomato, grape, and apple pulps alone or in combination as a seedling growing medium for tomato, cucumber, and pepper were investigated.

2. Material and Methods

2.1. Greenhouse experimental area

This research was conducted in 2021 at Tokat Gaziosmanpaşa University (TOGU) Research and Application Center's greenhouse facilities. The compost production phase finished in 2020, and thereafter, compost materials underwent testing in a seedling study for tomato, pepper, and cucumber cultivation. The study aimed to analyse the implications of different compost applications as a growing medium on these seedlings. The study was conducted in the province of Tokat, situated in the Central Black Sea Region, between the Black Sea Region, and Central Anatolia Region. Its coordinates are 39°51' - 40°55' North latitude and 35°27' - 37°39' East longitude. Tokat is bordered by Samsun to the north, Ordu to the northeast, Sivas to the south and southeast, Yozgat to the southwest, and Amasya to the west.

The seedling trials were conducted in a greenhouse that had a total enclosed area of 2000 m², with 1000 m² dedicated to seedling production. The greenhouse was equipped with a heating system, a fully automated fertilization system, and had a height of 5 meters under the gutter, with polycarbonate sides, and a roof coated with polyethylene (Figures 1 & 2).

Figure 1- Exterior view of the greenhouse

Figure 2- Seedbed and full automation system

2.2. Materials used in composting

The composts utilised in this study were produced using raw materials procured from diverse organizations in Tokat. The apple, and grape pulps were sourced from Dimes Gıda San. ve Tic. A.Ş., a fruit juice factory, whilst the tomato pulp was acquired from Kazova Tomato Paste Factory. During the composting process, fresh cattle manure, slaked lime, wheat straw, urea, soil, and water were blended with the tomato, apple, and grape pomace.

2.3. Plant materials used in the trial and their properties

The seedling trial comprised Asalet F1 (Hazera) tomatoes, İstek F1 (Yüksel Seed) bell peppers, and Olay F1 (AG Seed) cucumbers. Asalet F1 tomato cultivar is ordinarily cultivated in open fields, and is ideal for cultivation during spring, and summer. It is characterized as medium-early, producing vibrant red fruits weighing between 220-260 g on average. This variety displays considerable resistance to races of *Verticilium albo-atrum* (*Va*), *Verticilium dalie* (*Vd*), and *Fusarium oxysporum (Fol 0.1)*, as well as demonstrating tolerance to Tomato spotted wilt virus (TSWV), and *Meloidogyne arenaria* (*Ma*), *Meloidogyne incognita* (*Mi*), and *Meloidogyne javanica* (*Mj*).

The İstek F1 bell pepper cultivar boasts a long shape, and a sturdy plant structure, with an early maturation period. The fruit, which is around 8x4 cm in size, and thin-skinned, is green, and suitable for cultivation in both greenhouse, and open field environments during spring, and autumn. This cultivar also demonstrates tolerance to Tomato spotted wilt virus (TSWV).
The Olay F1 cucumber belongs to the Beith Alpha (Mini Type Cucumber) category, and is a compact, early variety ideal for greenhouse cultivation during spring, summer, and early autumn. The fruits are cylindrical, with long stalks, fewer veins, and necks, a medium-green hue, and an extended shelf life. They range from 18 to 20 cm long, and have been noted to exhibit resistance to Zucchini yellow mosaic virus (ZYMV). The fruit pictures of the varieties are given in Figure 3.

Figure 3- Varieties used in the study

2.4. Composting

A composting pre-study was executed in 2019, composting tomato, apple, grape, and peach pomace. However, due to peach pomace's high moisture content, and low aeration level, the preliminary trial was unsuccessful in producing any beneficial compost material. Consequently, peach compost was not featured in the subsequent trial. In the initial test, the decision was made to create compost from grape, apple, and tomato residue, whose composting process was successful. The collection of the pulp was procured for composting in 2021, resulting in a successful outcome.

The composting technique, as proposed by Stoffella & Kahn (2001), and Diacono & Montemurro (2019), was adapted for the purpose of composting. The materials utilised in the composting process were weighed, and measured in accordance with their volume. The grape, apple, and tomato pulps were measured as 2 m^3 each and placed on a concrete floor. 200 kg fresh dry cattle manure, 100 kg dry straw (in the form of compressed bales), 5 kg urea, and 5 kg slaked lime powder were added as main materials. The mixture was homogenised via a manure separator. The piles were mixed three times a week during the first month, and twice a week in subsequent periods. A sprinkler system was utilized during mixing, with watering continuing until the moisture content reached approximately 50% as measured by a moisture meter. Once the raw material became uniform on the concrete floor, it was piled to a height of one metre, and covered with transparent plastic. The compost pile was mixed on a weekly basis, and watered to achieve a 50% moisture content before being covered again. The temperature of the compost was measured daily using a soil temperature meter at a depth of 50 cm. The mixture was adjusted, and moisture content regulated until the temperature of the compost stabilized. After 22 weeks of composting, the mixing process concluded, and the plastic cover over the compost was removed to allow airing, and drying. The compost was then dried to reach 20% moisture content with a moisture content meter and stored for the trial.

Composts obtained from the remains of tomato, apple, and grape, along with different combinations of peat and perlite, were utilized as the cultivation medium in the experiment. After reaching maturity, the compost materials were filtered using a 4 mm sieve and subsequently utilized to generate seedling production media (Figure 4).

Figure 4- Compost types used in the study

Table 1- Ingredients of apple, grape and tomato compost (Anonymous 2021)

Analysis	*Apple compost*	*Grape compost*	*Tomato compost*
Moisture %	71.55	48.77	47.01
Organic matter %	59.11	68.82	55.58
pH	7.84	8.52	8.68
EC (dS/m)	6.10	2.51	5.84
Bacteria count	$3.60*10^7$	$4.75*10^6$	$3.85*10^7$
Total Nitrogen (N) (%)	4.09	2.71	3.06
Total Phosphorus (P) (%)	0.88	0.58	0.68
Total Potassium (K) (%)	2.85	3.26	1.38
Total Calcium (Ca) (%)	8.91	6.54	15.8
Total Magnesium (Mg) (%)	1.17	0.72	1.10
Total Iron (Fe) (%)	0.29	0.71	0.75
Total Zinc (Zn) (ppm)	200	250	170
Total Manganese (Mn) (ppm)	288	204.5	360
Total Copper (Cu) (ppm)	200	210	180

The investigation determined that the moisture content of compost produced from apple, grape, and tomato pulps utilized in food waste management were as follows: 47.01% for tomato compost, 71.55% for apple compost, and 48.77% for grape compost. Data displayed in Table 1 reveals that tomato compost holds 55.58% whereas apple, and grape compost contain 59.11% and 68.82%, respectively. Additionally, the pH ratios for tomato, apple, and grape compost are 8.68, 7.84, and 8.52, respectively. The electrical conductivity (EC) ratios for tomato, apple, and grape compost were 5.84, 6.10, and 2.51, respectively. Lastly, the bacterial counts for tomato, apple, and grape compost were 3.85 x 107, 3.60 x 10^7, and 4.75 x 10^6, respectively.

In this study, Çerçioğlu et al. (2017) found that the organic matter content was 30%, with a pH of 8.79, and EC of 11.72. Demir et al. (2010) reported a moisture content of 31.8%, organic matter ranging between 35-45%, and pH levels of 7.2-7.4, alongside a bacterial count of $1.5*10^{12}$. Black et al. (2014) found a bacterial count ranging between $1.4*10^8$ – $6.6*10^7$. Varank (2006) reported the organic matter content to be 36.7%, with a pH of 7.7, and moisture content ranging between 35-40%. Baltazar et al. (2013) discovered that the proportion of organic matter was 49.7%, with a pH of 8.33 and electrical conductivity (EC) of 6.10. Abad et al. (1993), on the other hand, found that the EC ranged between 0.59-1.38, and the pH between 7.3-6.1. Finally, Hussain et al. (2015) determined a moisture content of 42%.

Nutrient content is a significant factor in both compost production and utilization. The experiment employed diverse compost materials, with nitrogen ranging from 2.71% to 4.09%, phosphorus between 0.58% and 0.88%, and potassium ranging from 1.38% to 3.26%. Table 1 presents the macro, and micronutrient contents of the tested composts. The nitrogen, phosphorus, and potassium levels in the composts used in the experiment were comparable to or exceeded those found in previous studies. This can be attributed to the compost's composition and structure.

Various studies have found differing levels of nitrogen content in compost. Pathak et al. (2017) identified a concentration of 1.31%, while Demir et al. (2010) recorded a range of 1.5-2.5%. Raclavska et al. (2021) measured a concentration of 4.3%, and Wu (2001) reported a value of 12.6%. Hussain et al. (2015) determined a concentration of 1.16%, while Abad et al. (1993) observed a range of 7%. 4-16.3%; Varank (2006) reported a value of 1.43%; Arikan & Öztürk (2005) measured a range of 2.1-2.2%; Çerçioğlu et al. (2017) found it to be 2.18%; Yağmur & Okur (2017) determined a value of 1.32%, while Lopez-Baltazar et al. (2013) recorded a value of 5.44%.

Raclavska et al. (2021) reported a phosphorus content of 0.1%, whereas Demir et al. (2010) found it to be between 2.0-2.5%. The study conducted by Varank (2006) found a phosphorus content of 0.77%, while Çerçioğlu et al. (2017) and Lopez-Baltazar et al. (2013) reported 0.13% and 1.07%, respectively. Hussain et al. (2015) found a phosphorus content of 1.84%, and Yağmur & Okur (2017) reported it as 0.30%. Regarding potassium content, Raclavska et al. (2021) discovered it to be 15.2%, whereas Demir et al. (2010) reported a range of 2.5-3.0%; Hussain et al. (2015) found a potassium content of 0.69%, and Yağmur & Okur (2017) stated content of 2.56%.

López-Baltazar et al. (2013) reported the pH content as 6.11-8.33, the EC value as 1.09-6.10 dS m-1 and the organic matter content as 49.7% to 72.0%.

2.5. Seedling planting and application

The three vegetable species utilized in the seedling trial were seeded on the 1st of April 2021. The plug trays utilized for sowing the seeds were covered with vermiculite, measuring 0.5 cm in thickness. After watering, the plug trays were wrapped in thin plastic before being transported to the germination room (Figure 5). The germination chamber was maintained at 20±2 °C and waiting times were species-specific. Cucumber seeds were kept for 36 hours, whereas tomato seeds were kept for 72 hours and pepper seeds for 96 hours. The plug trays were shifted to the seedling greenhouse and kept on tables at a height of 70 cm from the ground. Media filling, seed sowing, and watering of the capped multipots were carried out. The temperature of the seedling

greenhouse was maintained at 20/25±3 °C with periodic verification of day/night temperatures. No fertilization was administered from seed sowing until the emergence of the first true leaves. When the first true leaves appeared, irrigation with the nutrient solution was started. The pH of the irrigation water was adjusted to 5.9 and kept at the same pH until the harvest of the seedlings. When the first true leaves emerged, irrigation using a nutrient solution was initiated. The pH of the irrigation water was adjusted to 5.9 and maintained at that level until harvesting of the seedlings. Upon aligning the cotyledon leaves with the soil surface, irrigation with a nutrient solution began. The EC value was initially set at 1.4 dS/m during the first week, followed by 1.6 dS/m in the second week, 1.8 dS/m in the third week, and finally adjusted to 2 dS/m until the evaluation of seedling quality. Fertilization was adjusted using an automated system. The stock tanks were prepared by following the N:P:K:Ca:Mg 2.5:1.0:2.5:1.0:0.5 ratio. Four tanks, each containing NPK/micronutrients/Ca/acid, constituted the stock tanks. The seedlings received irrigation from a boom irrigation system.

Figure 5- Seed sowing process

Seedlings were selected once their cotyledon leaves had emerged, and their height was measured upon observation of the first true leaf. Paclobutrazol was administered in varying doses, and quantities according to the species to regulate the growth of seedlings, and promote maturation. As the seedling greenhouse was meticulously disinfected prior to use, no pests or diseases were observed during the seedling growth period. Seedlings were sprayed with preparations equivalent to metallic copper on the 20^{th} and 35^{th} days after sowing. Upon reaching planting maturity, the seedlings in the control plots were harvested for observations and measurements. This study examined the seedling height, hypocotyl length, hypocotyl diameter, number of leaves per seedling, root length, seedling dry matter, and root dry matter of tomato, cucumber and pepper plants. Cucumber seedlings were removed after 36 days, tomato seedlings after 45 days, and pepper seedlings after 51 days (Figure 6).

The experiment was conducted with three replications based on the random plot experimental design. In each replication, 50 seedlings were cultivated and measurements were taken from 10 randomly selected seedlings. The characteristics under analysis were seedling height (cm), which was measured and averaged from the root collar to the tip of the leaves across all plots. Stem length (in cm) was measured and averaged from the root collar to the cotyledon leaves of ten seedlings. Stem diameter (in mm) was measured and averaged from ten randomly selected seedlings in each plot, 1 cm above the root collar, with the use of a digital caliper. Leaf Count (leaves per plant) - The number of leaves on each plant was counted and averaged. To determine the number of leaves per seedling, ten seedlings were randomly selected from each plot, and their true leaves were counted and averaged. Root length was measured in centimetres by uprooting ten random seedlings in each plot, washing their roots with water, and measuring them with a ruler. The dry matter content of the seedlings was recorded as a percentage. The dry matter content of the roots was also measured as a percentage. The weight of the seedlings was measured both when wet and when dry to determine their dry matter content. The Seedling dry matter content was calculated using the formula Seedling dry matter content (%) = (Seedling dry weight/ Seedling wet weight) x 100. Firstly, the wet and dry weights of the roots were measured, then the dry matter content of roots (%) was calculated using the formula (%) = (Root dry weight/Root wet weight) x 100. Composting materials were mixed either singularly or in combination with each other, along with peat and perlite. In the experiment, 13 different compost mixture were tested including the control treatment (Table 2).

Figure 6- Initial emergence and development period of the seedlings

Table 2- Seedling growing medium

1.	Control (2:1 Peat: Perlite) (C)
2.	Grape compost (G)
3.	Apple compost (A)
4.	Tomato compost (T)
5.	Grape+Apple+Tomato compost (GAT)
6.	2:1 Grape compost: Perlite (G:P)
7.	2:1 Apple compost: Perlite (A:P)
8.	2:1 Tomato compost: Perlite (T:P)
9.	2:1 (Grape+Apple+Tomato compost): Perlite (GAT:P)
10.	1:1:1:1 Grape compost: Peat: Perlite (G:P:P)
11.	1:1:1:1 Apple compost: Peat: Perlite (A: P:P)
12.	1:1:1:1 Tomato compost: Peat: Perlite (T: P:P)
13.	1:1:1:1 (Grape+Apple+Tomato compost): Peat: Perlite (GAT:P:P)

Tomato and pepper seedlings were grown in 216-cell plug trays, while the cucumber seedlings were cultivated in 150-cell plug trays. The dimensions of the plug trays that were implemented in the experiment can be found in Table 3.

Table 3- Dimensions of the plug trays used in the experiment

Plug tray	*Cell width-length-height (cm)*	*Viol cell volume (cc)*	*Trays width (mm)*	*Trays length (mm)*
150 (70+80)	4*4*6.5	50	325+325	370+470
216 (108+108)	3.2*3.2*6.5	40	347+347	470+470

2.6. Statistical analysis

The data were subjected to analysis of variance by SPSS 18 program and the means were compared using the duncan multiple comparison test ($P \leq 0.05$).

3. Results and Discussion

3.1. Tomato seedling production

In the cultivation of tomato seedlings, the seedling height was 16.93 cm in the control treatment and varied between 11.57 cm and 17.27 cm in the compost treatments. The hypocotyl length measured 3.60 cm in the control treatment, while it varied between 2.97 cm and 4.63 cm in the compost treatments. Additionally, the stem diameter was 3.81 mm in the control treatment, but it varied between 3.63 mm and 4.86 mm in the compost treatments. Seedling height, hypocotyl length, hypocotyl diameter, and the number of leaves per seedling are the most important criteria among tomato seedling characteristics. When considering the seedling height, hypocotyl length, hypocotyl diameter, and the number of leaves in the experiment, two media options (GAT+P+P and G+P+P) closely resembled or served as alternatives to peat media for cultivating tomato seedlings. The other characteristics of the seedlings grown in these two growths media were similar to those of the seedlings grown in a peat growth media.

While the number of leaves of tomato seedlings was 3.60 in the control medium, it varied between 3.20 and 4.20 in the compost medium. Root length varied between 6.40 cm in the control medium and 6.23-9.53 cm in the compost medium, while seedling dry matter content ranged from 9.34% in the control medium to 7.30-10.46% in the compost medium. Additionally, root dry matter content varied from 5.51% in the control medium to 3.86-5.45% in the compost medium. Differences among treatments in hypocotyl length and seedling dry matter content were insignificant, while differences among treatments were significant in other traits. Seedling growth, quality parameters, and significance levels of differences according to the media are given in Table 4.

Seedling cultivation is a key sector in tomato production, and like cucumber cultivation, has recently gained significant importance. While peat has historically been the predominant growing medium, its severe drawbacks, including dependence on foreign sources, necessitate exploring sustainable, local and cost-effective alternatives. Therefore, there is a demand for sustainable, local and cost-effective options. Upon analyzing Table 4, it is evident that utilizing compost media as a substitute seedling growing medium to peat in tomato cultivation has resulted in notable success. Similar alternative media studies conducted for a prolonged period in tomato seedling farming also exist for cucumber. Castillo et al. (2004) utilized a mixture of 65% peat, 30% compost, and 5% perlite. Ceglie et al. (2011) employed the use of compost derived from olive pomace and green waste. Díaz-Pérez & Camacho-Ferre (2010) utilized compost obtained from urban waste, vegetable waste, and grape pomace. Similarly, Carmona et al. (2012) successfully cultivated tomato seedlings using compost derived from grape waste. Tüzel et al. (2020) processed waste from olive plants to create compost, which was then mixed with peat in varying amounts to cultivate organic tomato seedlings.

The authors reported that the addition of 25% and 50% compost resulted in high-quality tomato plants. However, there are other successful alternatives to peat-based media for growing tomato seedlings, as indicated by previous studies. Considering the need for a single compost material in the current study, compost produced from grape pomace was found to be sufficient to rival peat, which is a commercial seedling growing medium, when mixed with perlite and peat.

Table 4- The effects of different composts and their mixtures on the quality of tomato seedlings

Media	*Seedling height (cm)*	*Hypocotyl length (cm)*	*Hypocotyl diameter (mm)*	*Leaf number per seedling (pcs. ***)*	*Root length (cm)*	*Seedling dry matter (%)*	*Root dry matter (%)*
Control (C)	16.93 ± 0.31a	3.60 ± 0.36	3.81 ± 0.20 de	3.60 ± 0.20c	6.40 ± 0.46 de	9.34 ± 2.08	5.51 ± 0.65 a
G	12.87 ± 0.99def	4.07 ± 0.15	4.24 ± 0.20 cd	3.67 ± 0.12bc	7.43 ± 0.60 bcd	8.46 ± 1.01	4.67 ± 0.27 abc
A	11.57 ± 0.96f	2.97 ± 0.55	3.63 ± 0.81 e	3.20 ± 0.35d	6.23 ± 0.70 e	8.92 ± 0.82	5.08 ± 0.30 ab
T	15.03 ± 0.45bc	3.73 ± 0.06	4.28 ± 0.23 bcd	3.87 ± 0.23abc	6.47 ± 0.31 de	9.38 ± 0.76	5.45 ± 0.50 ab
GAT	13.20 ± 0.53de	3.70 ± 0.10	4.48 ± 0.03 bc	4.00 ± 0.00ab	6.73 ± 0.23 de	8.81 ± 1.76	5.02 ± 0.21 ab
G+P	14.27 ± 0.67cd	4.37 ± 0.31	4.70 ± 0.28 abc	4.13 ± 0.31a	8.17 ± 0.38 b	7.63 ± 0.74	3.82 ± 0.48 c
A+P	12.97 ± 1.07def	4.26 ± 0.40	4.20 ± 0.37 cd	3.87 ± 0.23abc	7.33 ± 0.91 bcd	9.35 ± 1.21	3.86 ± 0.34 c
T+P	14.00 ± 0.80cde	3.07 ± 0.40	4.18 ± 0.21 cde	3.87 ± 0.12abc	6.60 ± 0.44 de	8.29 ± 1.66	5.38 ± 0.99 ab
GAT+P	13.40 ± 0.20de	3.50 ± 0.17	4.37 ± 0.06 bcd	3.87 ± 0.12abc	7.13 ± 0.58 cde	10.46 ± 0.30	4.52 ± 0.45 bc
G+P+P	16.13 ± 0.81ab	3.83 ± 0.06	4.45 ± 0.06 bc	4.00 ± 0.00ab	8.17 ± 0.51 b	8.68 ± 1.30	4.80 ± 0.28 ab
A+P+P	12.53 ± 0.21ef	3.60 ± 0.30	5.10 ± 0.29 a	3.93 ± 0.12abc	8.20 ± 0.36 b	7.30 ± 0.76	4.88 ± 0.55 ab
T+P+P	17.27 ± 0.95a	4.63 ± 0.73	4.86 ± 0.22 ab	4.20 ± 0.20a	9.53 ± 0.83 a	7.62 ± 1.51	4.94 ± 0.56 ab
GAT+P+P	16.33 ± 1.40ab	3.90 ± 0.10	4.71 ± 0.30 abc	4.13 ± 0.31a	8.03 ± 0.15 bc	7.82 ± 0.73	4.74 ± 0.33 abc
P- values	***	ns	***	***	***	ns	**

C: Control **G:** Grape, **A:** Apple, **T:** Tomato, **GAT:** Grape-Apple-Tomato, **G+P:** Grape+Perlite, **A+P:** Apple+Perlite, **T+P:** Tomato+Perlit, **GAT+P**: Grape-Apple-Tomato+Perlite, **G+P+P:** Grape+Peat+Perlite, **A+P+P:** Apple+Peat+Perlite, **T+P+P:** Tomato+Peat+Perlite, **GAT+P+P:** Grape-Apple-Tomato+Peat+Perlite, *****:** P<0.001, ****:** P<0.01, ***:** P<0.05, **ns:** insignificant

3.2. Cucumber seedling production

The most important quality characteristics of vegetable seedlings include height, hypocotyl length and diameter, as well as root length. In this study, the above-mentioned characteristics were taken into consideration as the criteria for ready-to-plant seedlings, and the media in which seedlings with similar characteristics to the control seedlings were obtained were accepted as an alternative to peat and perlite media.

In this study, which investigated the possibility of using compost materials instead of peat in seedling production, the seedling height of cucumber was 16.57 cm in the control plants, while it varied between 11.93 cm, and 20.13 cm in the compost treatments. Treatments with seedling heights between 15.50 cm, and 17.00 cm were accepted as equivalent to the control medium and accordingly seedling heights in 3 growing media grape (G), apple (A) and grape:perlite (G:P) were similar or alternative to the control treatment. The fact that the seedling height of most of the compost media in the experiment was higher than the control due to the higher organic matter and nitrogen content of compost than peat media. Seedling height is the most important criterion for deciding whether the growing medium is suitable or not. Apart from seedling height, hypocotyl length, hypocotyl diameter and number of leaves per seedling should also be taken into consideration. Other parameters other than these characteristics examined in the experiment can only be taken into consideration in addition to seedling height. The effects of growing media on cucumber seedling characteristics are given in Table 5.

The table shows that the hypocotyl length of cucumber seedlings was 3.67 cm in control and 3.10 to 4.30 cm in compost media, hypocotyl diameter was 6.04 mm in control, and 5.37 mm to 6.18 mm in compost media, the number of leaves per seedling was 4.60 in control, and 3.27 to 4.47 in compost media, the seedling height was 16.57 cm in control and 10.63 to 20.13 cm in compost media, root length 12.67 cm in control, and 8.53 cm and 13.73 cm in compost media, seedling dry matter content between 8.00% in control, and 6.19% and 8.81% in compost media and root dry matter content between 1.53% in control, and 1.51% and 3.00% in compost media.

Table 5- The effects of different composts and their mixtures on the quality of cucumber seedlings

Media	*Seedling height (cm)*	*Hypocotyl length (cm)*	*Hypocotyl diameter (mm)*	*Leaf number per seedling (pcs.***)*	*Root length (cm)*	*Seedling dry matter (%)*	*Root dry matter (%)*
Control (C)	16.57 ± 0.50 de	3.67 ± 0.21de	6.04±0.30 a	4.60±0.00 a	12.67 ± 1.85abc	8.00 ± 1.59 abc	1.53 ± 0.18d
G	10.63 ± 0.42 g	4.03 ± 0.05abc	5.89±0.29 ab	4.30±0.26 bc	13.27 ± 0.06a	7.46 ± 0.75 a-d	2.34 ± 0.18bc
A	15.67 ± 0.12 e	3.50 ± 0.20ef	6.10±0.30 a	4.17±0.06 bc	11.67 ± 0.70cd	6.67 ± 0.37 cd	2.06 ± 0.32bcd
T	17.60 ± 0.35 bcd	3.77 ± 0.06cde	5.98±0.09 a	4.20±0.00 bc	13.73 ± 0.12ab	7.41 ± 0.35 a-d	2.40 ± 0.35b
GAT	18.53 ± 0.50 b	3.77 ± 0.06cde	5.96±0.10 ab	4.17±0.06 bc	13.67 ± 0.61a	6.49 ± 0.50 cd	1.51 ± 0.28d
G+P	16.73 ± 0.58 cde	4.15 ± 0.08ab	5.88±0.26 ab	4.17±0.06 bc	11.57 ± 0.49cd	6.67 ± 0.81 cd	2.14 ± 0.22bc
A+P	15.60 ±1.22 E	3.23 ± 0.06f	5.37±0.33 c	4.23±0.15 bc	8.53 ± 0.35 e	8.49 ± 0.06 ab	1.83 ± 0.31cd
T+P	12.13 ± 0.31 F	3.10 ± 0.10f	5.51±0.35 c	4.40±0.20 ab	10.90 ± 0.70d	8.81 ± 0.76 a	1.84 ± 0.14cd
GAT+P	20.13 ± 1.85 A	4.30 ± 0.10a	6.18±0.12 a	4.07±0.23 c	11.93 ± 0.31bc	7.51 ± 0.67 a-d	2.40 ± 0.26b
G+P+P	13.27 ± 0.64 F	3.73 ± 0.40de	5.74±0.28 abc	4.47±0.31 ab	10.87 ± 1.24d	8.69 ± 1.24 a	2.47 ± 0.32b
A+P+P	18.07 ± 1.22 Bc	3.90 ± 0.00bcd	5.79±0.15 abc	4.17±0.06 bc	12.93 ± 0.90abc	7.10 ± 0.98 bcd	2.10 ± 0.16bc
T+P+P	18.73 ± 0.23 B	3.87 ± 0.06bcd	6.07±0.23 a	4.23±0.15 bc	12.67 ± 0.42abc	6.19 ± 0.85 d	1.79 ± 0.19cd
GAT+P+P	11.93 ± 0.31 Fg	4.13 ± 0.15ab	6.15±0.17 a	3.27±0.12 d	11.93 ± 0.31bc	7.28 ± 0.60 a-d	3.00 ± 0.58a
P- values	***	***	*	***	***	**	***

C: Control **G:** Grape, **A:** Apple, **T:** Tomato, **GAT:** Grape-Apple-Tomato, **G+P:** Grape+Perlite, **A+P:** Apple+Perlite, **T+P:** Tomato+Perlit, **GAT+P**: Grape-Apple-Tomato+Perlite, **G+P+P:** Grape+Peat+Perlite, **A+P+P:** Apple+Peat+Perlite, **T+P+P:** Tomato+Peat+Perlite, **GAT+P+P:** Grape-Apple-Tomato+Peat+Perlite,*****:** P<0.001, ****:** P<0.01, ***:** P<0.05, **ns:** insignificant.

It was important to investigate all treatments in the experiment to identify alternative media to the control treatment. Considering the other seedling parameters in Table 5, grape compost and perlite at a ratio of 2:1 and apple compost and perlite at a ratio of 2:1 were the most serious alternatives to the control in cucumber seedling cultivation. Although the use of apple compost without the addition of perlite also gives successful results, it is generally preferred to add perlite to the medium for homogeneous aeration of the root zone.

Sawan et al. (1997) found that composted sawdust yielded similar or superior results when compared to the control using 1:1 peat moss and vermiculite, for cucumber seedling production, plant height, number of leaves, chlorophyll content, fruit yield, and number of fruits per plant. The study concludes that sawdust compost can be used as a substitute for peat moss media at a high rate for cucumber seedling production.

Abdel-Razzak et al. (2019) study revealed that substrate mixtures enhanced with 5% and 10% tomato waste compost resulted in the best seedling response, accelerating seed germination and improving seedling morphology. These findings propose tomato waste compost as a viable replacement for peat.

Bayoumi et al. (2019), who tested compost derived from grape fruit waste as a cucumber seedling medium, found that grape compost can be successfully used instead of peat in cucumber seedling culture when mixed with coconut fibre or vermiculite in a 1:1 ratio. The data and conclusions of the researchers were demonstrated in this study conducted on cucumber seedlings, and compost was an important alternative to peat in cucumber seedling cultivation.

3.3. Pepper seedling production

The variations among treatments are statistically significant except for the number of leaves in pepper. Table 6 displays the significance levels of differences for quality parameters and seedling growth across different media. Seedling height of the pepper in the control treatment was 10.87 cm, while seedling height ranged from 12.73 cm to 18.00 cm in compost media during pepper seedling cultivation. The length of the hypocotyl was 2.07 cm in the control group, whereas it ranged from 2.27 cm to 3.67 cm in the compost groups. The hypocotyl diameter measured 2.43 mm in the control treatment, while it varied between 2.53 mm and 3.16 mm in the compost treatments. Among various seedling characteristics in pepper, seedling height, hypocotyl length, hypocotyl diameter, and number of leaves per seedling are considered significant criteria. According to the research, apple compost was found to be the nearest or equivalent alternative to peat for the cultivation of pepper seedlings.

The other characteristics of the seedlings grown in this medium were similar to the seedlings grown in the peat medium. In the experiment, while the number of leaves of pepper seedlings was 5.00 in the control medium, it varied between 5.87, and 7.07 in the compost medium. Root length varied between 5.90 cm in the control medium and between 5.00 cm and 8.20 cm in the compost medium, seedling dry matter content was 9.66% in the control medium and between 7.20% and 10.40% in the compost medium, root dry matter content was 3.44% in the control medium and between 2.82% and 6.95% in the compost medium.

Table 6- The effects of different composts and their mixtures on the quality of pepper seedlings

Media	*Seedling height (cm)*	*Hypocotyl length (cm)*	*Hypocotyl diameter (mm)*	*Leaf number per seedling (pcs. ns)*	*Root length (cm)*	*Seedling dry matter (%)*	*Root dry matter (%)*
Control (C)	10.87 ± 0.12 f	2.07 ± 0.15 f	2.43 ± 0.15 d	5.00 ± 0.53	5.90 ± 0.46 cd	9.66 ± 0.82 ab	3.44 ± 0.63 e
G	16.60 ± 0.60 ab	2.87 ± 0.06 bcd	3.16 ± 0.13 a	6.20 ± 1.11	7.00 ± 1.35 abc	7.86 ± 0.88 cde	5.40 ± 0.80 bc
A	12.73 ± 0.50 e	2.27 ± 0.38 ef	2.74 ± 0.19 bc	5.93 ± 0.31	5.00 ± 0.56 d	10.40 ± 0.09 a	6.37 ± 0.32 ab
T	14.13 ± 0.42 d	2.57 ± 0.21 de	2.87 ± 0.17 ab	6.07 ± 0.31	6.43 ± 0.29 bc	8.25 ± 0.69 b-e	3.67 ± 0.21 de
GAT	18.00 ± 0.72 a	3.20 ± 0.17 bc	3.03 ± 0.24 ab	6.27 ± 0.31	8.20 ± 0.17 a	9.15 ± 1.77 a-d	5.54 ± 1.05 bc
G+P	15.53 ± 0.23 bcd	2.93 ± 0.32 bcd	2.95 ± 0.09 ab	6.07 ± 0.31	6.13 ± 0.71 bcd	8.77 ± 0.58 b-e	3.52 ± 1.11 e
A+P	14.67 ± 0.12 cd	2.35 ± 0.13 ef	2.53 ± 0.06 cd	5.87 ± 0.50	6.50 ± 0.50 bc	9.37 ± 0.32 abc	2.84 ± 0.31 e
T+P	17.80 ± 0.69 a	3.67 ± 0.12 a	3.12 ± 0.13 a	7.07 ± 0.23	6.77 ± 0.31 bc	8.16 ± 0.24 b-e	2.82 ± 0.06 e
GAT+P	15.73 ± 0.81 bc	3.20 ± 0.26 bc	3.16 ± 0.17 a	6.73 ± 0.50	7.27 ± 0.42 ab	9.66 ± 0.90 ab	6.95 ± 0.39 a
G+P+P	16.60 ± 197 ab	2.80 ± 0.30 cd	3.04 ± 0.16 ab	6.40 ± 0.35	8.20 ± 0.35 a	7.20 ± 0.57 e	3.44 ± 0.82 e
A+P+P	14.87 ± 0.99 cd	2.90 ± 0.10 bcd	2.97 ± 0.23 ab	6.33 ± 0.42	7.30 ± 1.23 ab	8.29 ± 1.39 b-e	3.95 ± 1.08 de
T+P+P	17.53 ± 0.76 a	2.93 ± 0.15 bcd	3.02 ± 0.22 ab	6.20 ± 0.53	7.30 ± 0.56 ab	8.73 ± 0.31 b-e	3.74 ± 0.34 de
GAT+P+P	15.73 ± 0.81 bc	3.27 ± 0.32 b	3.16 ± 0.17 a	6.87 ± 0.58	7.27 ± 0.42 ab	7.75 ± 0.55 de	4.89 ± 0.82 cd
P- values	***	***	***	**ns**	**	*	**

C: Control **G:** Grape, **A:** Apple, **T:** Tomato, **GAT:** Grape-Apple-Tomato, **G+P:** Grape+Perlite, **A+P:** Apple+Perlite, **T+P:** Tomato+Perlit, **GAT+P**: Grape-Apple-Tomato+Perlite, **G+P+P:** Grape+Peat+Perlite, **A+P+P:** Apple+Peat+Perlite, **T+P+P:** Tomato+Peat+Perlite, **GAT+P+P:** Grape-Apple-Tomato+Peat+Perlite, ***:** P<0.001, **:** P<0.01, *:** P<0.05, **ns:** insignificant.

Table 6 demonstrates that apple compost is a viable alternative growing medium to peat for pepper seedlings. It is essential to follow hygiene regulations during the cultivation of pepper seedlings. Studies on alternative growing media to peat have also been undertaken for other vegetable species in pepper cultivation. Lee et al. (2000) successfully cultivated pepper seedlings using a mixture of 40% peat and 60% paddy husk. Marques et al. (2014) achieved similar success with a combination of perlite, peat, perlite + peat, and mushroom compost. Additionally, Chrysargyris et al. (2017) utilized municipal solid waste compost, and Carmona et al. (2012) utilized compost obtained from grape waste in the cultivation of pepper seedlings.

4. Conclusions

Türkiye is a prominent global producer of commercial vegetable seedlings. The growth of these seedlings involves a mixture of peat, and perlite in a ratio of 2:1 or 3:1. As imported peat is frequently employed in seedling cultivation, multiple research studies have aimed to identify alternative materials. The most promising option in this context is compost material obtained from organic waste. The study examined thirteen diverse growing media, including pure, and mixed variations, using a 2:1 peat:perlite combination as a control group. The seedlings of tomato, pepper, and cucumber cultivated with grape, and apple composts demonstrated corresponding outcomes to those grown in the control group. In particular, the treatments using solely apple or grape composts, or a combination of both, exhibited superior performance in comparison to the control treatment.
In the seedling trial conducted in 2021, compost derived from apple, and grape pomace yielded superior outcomes in growing tomato, pepper, and cucumber seedlings compared to the control treatment (peat-perlite). No indications of soil-borne diseases were detected upon using compost. Despite adequate quantities of apple, and grape pomace in Türkiye, the shortage of compost production employing these materials has been established as a significant shortcoming.

References

Abad M, Martinez P F, Martinez M D & Martinez J (1993). Evaluacion agronomica de los sustratos de cultivo (Agronomic evaluation of substrates). Acta Hort. 11: 141–154

Abdel-Razzak H, Alkoaik F, Rashwan M, Fulleros R & Ibrahim M (2019). Tomato waste compost as an alternative substrate to peat moss for the production of vegetable seedlings. *Journal of Plant Nutrition* 42(3): 287-295

Anonymous (2021)**.** Central Research Institute of Soil, Fertiliser and Water Resources. Plant and Organic Fertiliser Laboratory. Yenimahalle/Ankara. toprakgubresu@tarim.gov.tr.

Aydeniz A & Brohi A (1991). Fertilizers and Fertilization. C.U. Tokat Faculty of Agriculture Publications No: 10, Textbook: 3, Tokat.

Baltazar J L, Méndez-Matías A, Pliego-Marín L, Aragón-Roble E & Robles-Martínez M L (2013). Agronomic evaluation of substrates in pepper seedlings 'onza' (Capsicum annuum) in greenhouse. (Evaluación agronómica de sustratos en plántulas de chile 'onza' (Capsicum annuum) en invernadero). Revista Mexicana de Ciencias Agrícolas Pub. E sp. N úm. 6 14 de agosto - 26 de septiembre, 2013 pp. 1139-1150

Bayındır Ş, Şahin S & Uysal F (2004). Farm manure use potential in Türkiye. Türkiye III. National Fertilizer Congress Agriculture-Industry-Environment, 11-13 October 2004, Tokat, 735 pp

Bayoumi Y A, El-Henawy A S, Abdelaal K A ve Elhawat N (2019). Grape fruit waste compost as a nursery substrate ingredient for high-quality cucumber (Cucumis sativus L.) seedlings production. Compost Science & Utilization 27(4): 205-216

Benito M, Masaguer A, De Antonio R & Moliner A (2005). Use of pruning waste compost as a component in soilless growing media. Bioresource Technology 96(5): 597-603

Benito M, Masaguer A, Moliner A & De Antonio R (2006). Chemical and physical properties of pruning waste compost and their seasonal variability. Bioresource Technology 97(16): 2071- 2076

Bhattacharyya P, Chakrabarti K & Chakraborty A (2003). Residual effects of municipal solid waste compost on microbial biomass and activities in mustard growing soil. Archives of Agronomy and Soil Science 49: 585-592

Black A R, Taraba L J, Day G B, Damasceno A F, Newman C M, Akers K A, Wood C L, McQuerry K J & Bewley J M (2014). The relationship between compost bedded pack performance, management, and bacterial counts. J. Dairy Sci. 97: 2669–2679 http://dx.doi.org/10.3168/jds.2013-6779.

Carmona E, Moreno T M, Aviles M & Ordovas J (2012). Use of grape marc compost as substrate for vegetable seedlings. https://doi.org/10.1016/j.scienta.2012.01.023.

Castillo J E, Herrera F, López-Bellido R J, López-Bellido F J, López-Bellido L & Fernández E J (2004). Municipal solid waste (MSW) compost as a tomato transplant medium. Compost Science & Utilization, 12(1): 86-92

Ceglie F G, Elshafie H, Verrastro V & Tittarelli F (2011). Evaluation of olive pomace and green waste composts as peat substitutes for organic tomato seedling production. Compost Science & Utilization, 19(4): 293-300

Chrysargyris A, Stamatakis A, Moustakas K, Prasad M & Tzortzakis N (2017). Evaluation of Municipal Solid Waste Compost and/or Fertigation as Peat Substituent for Pepper Seedlings Production. pp. 2285-2294-2017

Çerçioğlu M, Yağmur B, Kara S R & Okur B (2017). The Effect of Agro-Industrial Compost and Barn Manure on Some Chemical Properties of Soil and Yield in Pepper (Capsicum annuum L.) Cultivation. *Ege Univ. Fak. of Agric. Derg.* 2017: 54(1): 71-77

Demir H, Polat E & Sönmez İ (2010). A New Organic Fertiliser for Our Country: Vermicompost. Agriculture Actual (14): 54-60 April 2010.

Díaz-Pérez M & Camacho-Ferre F (2010). Effect of composts in substrates on the growth of tomato transplants. HortTechnology 20(2): 361-367

Diacono M & Montemurro F (2019). Olive pomace compost in organic emmer crop: yield, soil properties, and heavy metals' fate in plant and soil. Journal of Soil Science and Plant Nutrition 19(1): 63-70

Entry J A, Wood B H, Edwards J H & Wood C W (1997). Influence of organic by-products and nitrogen source on chemical and microbiological status of an agricultural soil. Biology and Fertility of Soils 24: 196-204

Frolking S, Roulet N T, Moore T R, Richard P J H, Lavoie M & Muller S D (2001). Modeling northern peatland decomposition and peat accumulation. Ecosystems 4: 479-498

Gül A (2008). Soilless Agriculture, Hasad Publishing, 144 pp İstanbul

Hussain S S, Baba J A, Zubair N, Nissa R & Misger F A (2015)**.** Quality evaluation of chemically-enriched compost, vermicompost and conventional compost. *An Asian Journal of Soil Science*. doi: 10.15740/Has/Ajss/12.1/66-70.

Lee J, Lee B, Lee Y & Kim K (2000). Growth and inorganic element contents of hot pepper seedlings in fresh and decomposed expanded! rice hull-based substrates. J. Kor. Soc. Hort. Sci. 41: 147-151

Leonardi C (2004). Growing media. Regional Training Workshop on Soilless Culture Technologies. pp. 83-92 3-5 March, İzmir-Türkiye.

López-Baltazar J, Méndez-Matías A, Pliego-Marín L, Aragón-Robles E & Robles-Martínez M L (2013). Agronomic evaluation of substrates in pepper seedlings 'onza' (Capsicum annuum) in greenhouse. Revista Mexicana de Ciencias Agrícolas Pub. Esp. Núm. 6 14 de agosto - 26 de septiembre, 2013 pp. 1139-1150

Madejon E R, Lopez J, Murillo M & Cabera F (2001). Agricultural use of three (sugar-beet) vinasse composts: Effect on crops and chemical properties of a Cambisol soil in the Guadalquivir river valley (SW Spain). Agriculture, Ecosystem and Environment 84: 55-65

Marques E L S, Martos E T, Souza R J, Silva R, Zied D C & Souza Dias E (2014). Spent Mushroom Compost as a Substrat as a Substrat for Production of Marul Fideleri, *Journal of Agriculture Science* 6(7): 138- 143

Özenç N (2004). Effects of hazelnut shells and other organic matters on the properties of hazelnut growing soils and product quality. Ankara University, Institute of Science, PhD Thesis, 399 pages.

Özgüven M, Kaya Z, Yılmaz A M, Kırıcı S & Tansı S (1996). Evaluation of cigarette factory tobacco waste as fertilizer. *Turkish Journal of Agriculture and Forestry* 23(1): 43-51

Pascual J A, Ayuso M, Hernández T & García C A (1997). Phytotoxicity and fertilizer value of different organic materials. Agrochemical 41: 50-62

Sawan O M, Eissa A M & Abou-Hadid A F (1997, November). The effect of different growing media on cucumber seedling production, fruit yield and quality under greenhouse conditions. In International Symposium Greenhouse Management for Better Yield & Quality in Mild Winter Climates 491:369-376

Stoffella P J & Kahn B A (2001). Compost utilization in horticultural cropping systems. CRC press.

Tüzel Y, Boztok K & Eltez R Z (1992). Usage possibilities of waste compost. Türkiye IV. Edible Mushroom Congress (2-4 November 1992, Yalova) Volume 2 pp. 1-10

Tüzel Y (1996). Ecological Agriculture in the Greenhouse. (Ed: U. Aksoy & A. Altındişli), Ecological Agriculture Organization Association (ETO), Bornova, İzmir pp. 83-95

Tüzel Y & Gül A (2008). New Developments in Greenhouse. Aegean Agricultural Res. Ins. Publication No. 133, pp. 145-160

Tüzel Y, Ekinci K, Öztekin G B, Erdal I, Varol N & Merken Ö (2020). Utilization of olive oil processing waste composts in organic tomato seedling production. Agronomy 10(6): 797

Varank G (2006). Comparison of Aerobically Stabilised Solid Wastes and Compost Product. Yıldız Technical University Institute of Science and Technology. FBE Department of Environmental Engineering. [Published master's thesis], 128 pages. İstanbul, 2006

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A Synthesis on Agent-Based Impact Assessment Models from the Perspective of the EU Rural Development Policy Measures

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ABSTRACT
The second pillar of the European Union's (EU) Common Agricultural Policy (CAP) aims at supporting rural areas by meeting the economic, environmental and social challenges. To deal with these challenges, countries are faced with the question of selecting the best tools among a large set of policy instruments. The problem of choosing the best policy instruments is aggravated by the very heterogeneous character of the societal demands that differ among member countries with very different economic and institutional structures. This study aims to introduce the agent-based modelling platforms that have been widely used in the impact analysis of recent rural development policies in the EU in a comparative manner. It also aims to explain how the above-mentioned sources of heterogeneity are handled in these models. To achieve the stated objectives, the study first examines the historical development of rural development policies within the EU. Subsequently, it proceeds to analyse several agent-based platforms that have been employed for the purpose of assessing the impact of agricultural policies with respect to certain features such as integration of land market, modelling unit, decision rule, rules of exit, labour market and price formation. To conclude, it is observed that as the rural development policies are formulated on farm-basis and as farms have a heterogeneous structure within themselves, in addition, the expansion of databases and the development of empirical analysis tools and technologies have led to a shift in empirical analyses towards agent-based models. However, these modelling platforms still embody various problems, especially in terms of database adjustments and parameterization and calibration of the model.

Keywords: European Union, Rural development policies, Agent-based modelling

1. Introduction

The international empirical literature shows that studies of impact analysis and policy modelling regarding the agricultural sector are gradually shifting towards the use of agent-based methods. The two most important reasons behind this shift are that the policies are targeting more farms rather than sector and product, and the non-homogenous structure of the farms.

The agricultural and rural development policies of the EU set a very good stage for the above-mentioned reasons. Both the policies implemented within the Union have become increasingly farm-oriented and the farms within the Union exhibit an extremely heterogeneous structure.

From this perspective, the paper discusses the argument that agent-based models are more appropriate tools for impact analysis of changing agricultural and rural development policies in the EU. It does so within the framework of a literature review, thus providing both a broad overview of changing EU policies and an assessment of the advantages and disadvantages of agent-based models.

Due to the complexity of the agricultural sector and the many roles it plays, conducting an effect assessment on agricultural policies is no simple task. Although agriculture is the primary economic force in rural areas, the primary component in agricultural production -land- is increasingly being put to non-agricultural purposes. The industry is vital to the bio-economy

and has strong ties to cultural preservation, tourism, and rural development. One further distinctive trait is the sector's multidimensional linkage with the environment, which calls for consideration of such links in the impact assessment evaluations. The industry is also distinguished by its focus on organic species, which brings up questions of plant and animal welfare, biodiversity, and humane treatment of animals. Further complicating agricultural policy impact assessment is the fact that different countries are at different stages of development, which in turn affects the sector's and farms' structures, as well as farmers' management techniques. The institutional makeup and public expectations are both influenced by the level of development. Therefore, it becomes a significant difficulty to model policies affecting rural communities and the agricultural sector.

Since the inception of the Common Agricultural Policy (CAP) there has been a move from heavily interventionist to more market-oriented policies meaning a move towards decoupled, direct payments. There has been a shift in concerns from food security to more social and environmental aspects and to rural areas/development was also observed. Finally, a shift in interests from aggregate behaviour to farm behaviour took place. In terms of rural development policies again a few changes were observed simultaneously. These include; a change from limited farm restructuring measures towards multi-annual financial frameworks, from limited regional funds towards fundamental principles of regional funding and from agriculture–oriented policies towards reinforcement of rural development policies (rural policies to support non-agricultural actors). Moreover, a shift from regional policies towards rural policies, from economic concerns to sustainability of agricultural land use, a change towards promoting sustainable farming and innovation to support jobs and growth in rural areas and finally a move in financial assistance towards the productive use of land is also observed.

2. A Brief on the EU's Rural Development Policies

Since its effective inception in 1962, the CAP of the EU has undergone significant revisions. In most cases these reforms were attempts to remedy internal and external unforeseen outcomes of policies with regard to agricultural sector itself, rural livelihoods and environment. Sometimes societal demands that reflect the heterogeneity among member countries were the main factors behind modifications to the CAP.

Initial policies relied on price support, import taxes, and export subsidies to provide farmers with an appropriate environment for production. These measures also encouraged the widespread use of agricultural technologies like chemical fertilisers and mechanised harvesting, which ultimately led to higher crop yields. In place of price support, the 'MacSharry reform' of 1992 included hectare-based direct aid payments and compulsory set aside under the CAP. The MacSharry reform also encouraged environmentally conscious agricultural practises. Income support is provided on the condition that farmers take care of the land and meet food safety, environmental, animal health and welfare standards under the "Agenda 2000 reform," which acknowledged the multi-functionality of European agricultural systems (Emmerson et al. 2016), and the "decoupling" reform of the CAP in 2003. In 2007, the European Agricultural Fund for Rural Development was established, bolstering agro-environmental schemes. The 'health check' of the CAP in 2008, along with the elimination of arable set aside and the introduction of additional cross-compliance requirements, finalised decoupling. The "health check" resulted in a reduction of direct payments to farmers, with the money going instead into the Rural Development Fund. To better promote smart, sustainable, and equitable growth and to better contribute to the goals of Europe's 2020 strategy, the CAP underwent a significant change in 2013. The CAP 2014-2020 prioritised the conservation of agricultural land, the protection of biodiversity, and the regulation of climate change. These first two goals, together known as "Pillar I" of the CAP, deal with issues like rural development programmes and income support for farmers. In addition, the CAP regulations for the 2014–20 period will be extended under a transitional regulation that will also ensure an easy transition to the eventual framework of the CAP strategic plans (European Commission 2023).

3. A Summary on Alternative Empirical Approaches Used for Agricultural Impact Assessment

The literature provides a rich toolbox that includes various qualitative methods and quantitative models to use for policy impact assessment regarding the agricultural sector. If qualitative methods are left aside as these are not at the main focus of the paper, the quantitative modelling is carried out by various approaches. These include cost-benefit analysis, multi-criteria analysis, counterfactual analyses, life-cycle analyses, input-output models, micro-simulation models, econometric analysis, general equilibrium models, partial equilibrium models and integrated approaches. The temporal parameters of these tools vary in terms of time horizon and the choice between static and dynamic settings. Additionally, they differ in spatial resolution levels, ranging from plot, farm, parcel, region, to country. These tools also incorporate several components, including biophysical, environmental, and social factors. Furthermore, they possess additional distinguishing qualities, such as the inclusion of policy instruments. Certain colleagues employ alternative methodologies to categorise these quantitative instruments. Millington et al. (2017) used the term "telecoupling" as a means of describing the integration of agricultural markets with the environment and rural economies, both at local and global scales. The empirical approaches in question are categorised as partial equilibrium economic models, system dynamics modelling, and agent-based modelling. Rizojewa-Sileva et al. (2018) examine the topic via the lens of "simulation" and categorise the empirical techniques as system dynamics (including both partial and general equilibrium models), agent-based models, hybrid models, and discrete event simulation.

While policy impact assessment regarding agricultural sector is not an easy task and embodies various challenges, reviewing the alternative methodologies is difficult as well due to its wide coverage. Therefore, the methodologies has to be limited accordingly with the aim of the paper. In this review, our concern is not the modelling of individual events and therefore discrete event simulation methods is not elaborated. The use of hybrid models introduces new challenges such as extensive data requirement, theoretical consistency, and representation problems. Besides, each hybrid model is self-tailored to a specific problem and so comes with its own distinguishing and structural features. Hence hybrid models are not reviewed here either.

Due to the complexity of the topic, analysing alternative approaches for assessing the impact of policies on the agricultural sector is also a challenging task, and this paper's focus should be narrowed to avoid digressing. Discrete event modelling approaches are not expounded upon because it is not the focus of this review. Each hybrid model is self-tailored to a given problem and hence comes with its own differentiating and structural elements. These hurdles arise when using hybrid models and include a large amount of data, theoretical consistency, and representation issues. Consequently, hybrid models are not discussed further here.

4. The Aim and Plan of the Study

This review adopts the terminology of "agricultural modelling platforms" and places particular emphasis on agent-based models that do not incorporate any type of "representative behaviour in activities/countries/regions/land and or farm typologies". By narrowing the scope of empirical methods in this way, the study first describes the evolution of EU rural development policies and thus aims to justify the motivation of the study. Then, by comparatively reviewing agent-based models from various perspectives, it aims to show which aspects of these models are advantageous and which aspects are problematic in impact analyses.

After an introduction with a brief overview of the EU agricultural and rural development policies and alternative empirical methods, the study continues with a detailed review of these policies in the second section. The literature review provides a comprehensive overview of the fundamental and specific attributes of the agent-based approach in a comparative approach. The study concludes in the last section.

5. Evolution of the EU's Rural Development Policies (RDP)

Meeting the economic, environmental, and social challenges that rural areas face is the core objective of the EU's second pillar of the CAP. The RDP's primary goals are the enhancement of agricultural competitiveness; the sustainable management of natural resources; the mitigation of agriculture's effects on climate change and the creation of a climate-resilient agricultural sector; and the achievement of a territorially-balanced development through the maintenance of employment.

According to a standard definition, rural areas in the EU include 91% of the terrain and 56% of the total population. There are serious ecological and societal problems in many of these rural places. Agricultural methods strain the increasingly diverse rural ecosystem. The agricultural and food processing industries still contribute significantly to the economies of rural and peripheral communities. Public goods are created through agriculture and forestry, including scenic views, species richness, a steady climate, and safety from natural disasters. These concerns are the focus of the European Union's rural development programme (European Commission 2023).

The first element of the regional policy was European Social Fund (ESF) aiming at more employment and workers' mobility and rendering guidance section of FEOGA. Delors package developed in 1988 setting up and automatic budget system allowing longer term regional development strategies boosted the rural development role in the EU. The programme's guiding concepts were as follows: concentration, planning, collaboration and monitoring and evaluation of projects and programmes.

The goals of regional development include, among other things:

- The development and structural adjustment of underperforming regions.
- The revitalization of areas affected severely by industrial decline.
- Reducing long-term unemployment rates.
- Helping young people break into the workforce.
- Speeding up the restructuring of agriculture and fostering growth in rural areas (Table 1).

Commission announced its first rural development policy by the document called "The Future of Rural Society" first in 1988 (EC 1988). In parallel with the MacSharry programme, Commission launched a pilot programme for the rural development called LEADER. Following 2005's CAP Mid-Term Review, EC revised its rural development policy and beginning in 2007, the new policy went into implementation. There are many different initiatives under the EU's rural development policy, but they can be broken down into three main categories: 1) boosting the competitiveness of agriculture and forestry, 2) enhancing the environment and countryside by bolstering land management , and 3) enhancing the quality of life in rural areas and encouraging diversification of the rural economy (via the LEADER programme). Rural development funds clearly separated into a special subheading in 2007-2013 for financial perspective and programming period and it is not a part of the regional polices linked to the CAP.

As part of Agenda 2000's reforms, the Rural Development Regulation (EC Regulation 1257/99) was enacted to promote and support thriving rural communities, building on the multi-functionality and Living Countryside concept introduced in the Cork Declaration (EC 1996). It outlined three primary strategies (Renting et al. 2006).

1. Multi-functionality (i.e. paying farmers for the variety of services they give while emphasising the creation of other sources of income).
2. A multi-sectoral strategy to foster growth in rural areas' economies and societies.
3. Enhanced efficiency supported by strategically integrated and streamlined programmes endowed with the flexibility they require.

Table 1- Origins and Evolution of EU Regional and Rural Policy

1964	Launch of the CAP	Prioritise financial support.
1972	Introduction of Rural Development Funds	Implementation of limited agriculture reorganisation measures.
1975	Creation of Regional Funds	Introduction of inter-member state transfers.
1988	Delors I Package	Foundation of the current budget structure; introduction of multi-year financial frameworks and basic regional funding principles.
1992	Delors II Package	Significant increases in regional funding.
1992	MacSharry Reforms of the CAP	Introduction of direct payment mechanisms; elimination of price support; bolstering rural development policies.
1996	Cork Declaration	Introducing multifunctionality and the concept of a Living Countryside, as well as advising the Commission on policy orientations for an innovative, integrated, and inclusive rural and agricultural policy.
1999	Agenda 2000	Advancing the reform of the CAP.
2000	Lisbon Strategy	Concentrate on growth and employment via innovation.
2003	Mid-term Review of the CAP	Reform of agricultural markets and decoupling of direct income support from production in the CAP.
2005	Reform of Rural Development Policies	Expanding the scope of rural policies to include assistance for non-agricultural actors.
2007-onward	New EU Financial Perspectives	Budgetary reform, increased emphasis on employment and innovation.
2013	Treaty on the Functioning of the European Union (TFEU)	Promoting agricultural competitiveness; assuring sustainable natural resource management and climate action
2016	Cork 2.0 Declaration for 2020-27	Advising the Commission on the policy orientations for an innovative, integrated, and inclusive rural and agricultural policy, based on the Cork Declaration of 1996.
2020		Guidelines for rural development expenditures in 2021 and 2022.

Source: Adopted partly from FAO/WB. The Evolution and the Impact of EU Regional and Rural Policy, Working Paper, EU, 2016 and expanded by the authors.

Economic, social, and environmental policies for rural development are under the purview of the CAP's so-called "second pillar," which was first outlined in 1988 as part of Agenda 2000. The CAP's second pillar is meant to provide support to rural areas throughout the EU, and it is far more adaptable than the first. It's designed to tackle numerous economic, social, and environmental problems plaguing the modern world. By providing a European "menu of measures", it helps local, regional, and national authorities create their own multiannual rural development programmes. The rural development programmes are funded in part by the EU and in part by national or regional money, in contrast to the first pillar, which is funded solely by the EU (European Parliament 2023).

Rural development policy legally based on the Treaty on the Functioning of the European Union (TFEU); Regulation (EU) No 1303/2013 (common provisions concerning the European Structural and Investment Funds); Regulation (EU) No 1305/2013 (support for rural development); Regulation (EU) No 1306/2013 (financing, management and monitoring of the common agricultural policy); and the Omnibus Regulation (Regulation (EU) 2017/2393 (introducing changes to Regulation No 1305/2013 and 1306/2013).

Achieving sustainable management of natural resources and combating climate change are two further goals of the rural development policy, which also seeks to achieve a balanced territorial development of rural societies and economies. One component of this goal is the enhancement of steady employment. EU priorities for rural development policy in the 2014–2020 period are indicated as:

- Promoting knowledge transfer in the fields of agriculture, forestry, and rural areas.
- Improving the competitiveness of various agricultural sectors and ensuring the sustainability of farming operations.
- Enhancing food chain organisation and risk management in agriculture.
- Improving agricultural and forest ecosystems through restoration and preservation.

- Encouraging businesses in the agricultural, food, and forestry industries to become more resourceful and productive while also helping them make the transition to a low-carbon, climate-resilient economy.
- Encouraging economic growth, lowering rural poverty, and broadening social participation (European Parliament 2023).

Member states or member state regions design the rural development programmes through which rural development policy is implemented to meets the specific needs of member states. The programme has to relate at least to four of the six rural development priorities. A combination of measures for the programmes is selected from a 'menu' of European measures and the programme is co-financed by the FEOGA. The co-financing rates differ based on the region and measure concerned. The European Commission approves the programmes including a financing plan and a set of performance indicators. The programme is monitored and assessed by the Commission and the Member States with a joint system for rural development policy.

The 'European menu' includes the following options:

1. Methods of knowledge and information transfer (such as training and public awareness campaigns).
2. Consultation, farm management, and immediate support service for farmers.
3. Agricultural and food quality assurance systems (innovative approaches to farmer involvement in quality assurance systems).
4. Investment expenditures (on things like food processing, infrastructure, farm productivity and sustainability, and so on).
5. Restoring the potential for agricultural production lost due to disasters and catastrophic occurrences and implementing measures to prevent similar losses in the future.
6. Farm and company expansion (including assistance for new farmers and the establishment of non-agricultural firms in rural areas).
7. Reviving rural communities and providing essential services to them (high-speed internet, cultural events, tourism attractions, etc.).
8. Investing on the growth of forests and making them more sustainable (through reforestation and new forest creation).
9. Forming organisations and groups of producers.
10. Ensuring that environmentally and climate-friendly farming methods are maintained (agro-environment-climate measures) (which should be incorporated into rural development programmes).
11. Conversion or support payments for organic farmers.
12. The Water Framework Directive and the Natura 2000 system, and the related payments.
13. Compensation for regions with unique physical or social challenges.
14. Funding for animal welfare.
15. Conservation of forests, environmental services, and climate change compensation.
16. Encouraging cooperation between farmers and forestry operators and those involved in the food production chain (establishing centres and networks, operational groups of the European Innovation Partnership for Agricultural Productivity and Sustainability (EIP)).
17. Risk management toolkit including crop, livestock, and plant insurance; mutual funds for adverse climate events, animal and plant diseases, pest infestations, and environmental incidents; income stabilisation programmes" (European Parliament 2023).

About EUR 100 billion were set aside in the EU budget for rural development in the 2014-2020 multiannual financial framework, with another EUR 61 billion supplied by the Member States as national co-financing for such measures.

On January 1, 2018, the Omnibus Regulation took effect, drastically altering the pre-existing risk management framework. If a farmer's revenue drops by more than 20%, or if more than 20% of their annual average crop is lost, they may qualify for the sector-specific stabilisation tool.

Building on the Cork 2.0 Declaration on rural development (EU 2016), the EU released a new communication on the future of food and farming for the period of 2020-2027 on November 29th, 2017. The communication focused on the next generation of farmers and the importance of preserving natural resources and promoting sustainable development. Value chains in growing sectors including bio-economy, sustainable energy, the circular economy, and eco-tourism are highlighted as a new area of emphasis in this communication.

As part of the EU's cohesion policy, the regulations of the Leader programme have been incorporated into the cohesion policy framework, the FEOGA is no longer a structural fund, and the rate of co-financing from the Community budget has been reduced. The Farm to Fork and Biodiversity Strategy, as well as the European Green Deal, will all make significant use of agro-environmental and climatic strategies. While the Next Generation EU Fund will be increased to aid rural areas in making the necessary structural changes to achieve the objectives of the European Green Deal and the Digital Transition Pact, the overall budget for Pillar II has been cut by about 19% compared to the previous period (European Parliament 2023).

6. Notable features of RDPs

Adopted on December 23, 2020, the CAP transitional regulation lays out the rules for rural development expenditure in 2021-22. These rules are as follows:

1. Climate and environmental spending: Each RDP must allocate at least 30% of its budget to initiatives that address climate change and the environment.

2. Fostering local initiatives: At least 5% of RDP money must go towards initiatives using the LEADER / Community Led Local Development methodology.

3. Supporting smart villages: The smart villages programme seeks to offer a flexible toolkit to nurture, facilitate, and scale up innovation in rural areas, addressing the common difficulties residents confront in rural areas.

4. Financial tools: The EAFRD (European Commission) serves as a source for loans, microcredits, guarantees, and equity for financially viable projects fulfilling the EAFRD's aims.

A graphical illustration of the evolution of CAP was presented in Figure 1. Dark lines are the main CAP reforms introduced since 1962. Red lines represent the other changes during the implementation of CAP, basically indicating the rural development policies of the EU.

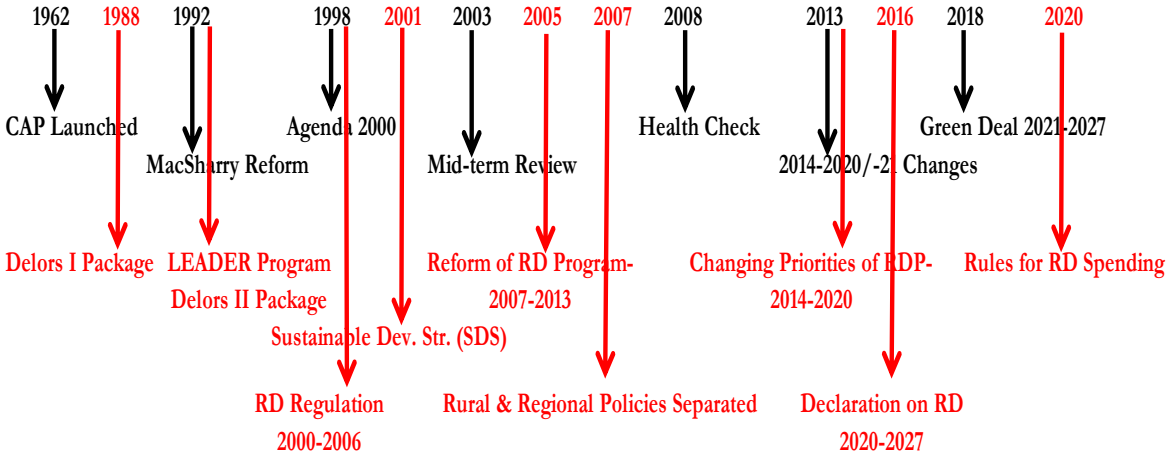

Figure 1- EU Agricultural Policy Evolution

7. Literature Review: Agent-Based Models (ABMs)

7.1. General characteristics of ABMs used for agricultural policy impact assessment

Modelling agricultural sector for policy impact assessment is becoming a real challenge due to both the sector's multi-functional characteristics and to the changing economic and institutional environment surrounding each country and regions. The multi-functionality covers economic, social and environmental dimensions. Parallel with these circumstances, policy objectives and instruments of the CAP have been shifting continuously from country/activity-based interventionist to farm-based decoupled payments in the last 50 years or so. Last couple decades also witnessed the changes in policy objectives that aim at preserving/improving environmental quality, increasing food safety/security and animal welfare standards and achieving more developed and viable rural areas.

From the above perspective, in the last decade a shift in modelling approaches used for policy impact assessment has been observed in the empirical literature towards farm-based approaches rather than country/region- and activity-based representative type models. Thus, it is foreseen that farm-based approaches (Hybrid modelling approaches that integrate various modelling platforms/capacities of different disciplines have been also increasing lately. These approaches can account for the economic, environmental, and social impacts at different spatial scales however parameterization and calibration of these modelling platforms might become the main challenge rather than policy modelling) will be capable of analysing the socio-economic and environmental impacts of agricultural policies at a much more disaggregated level. Figure 2 provides a summary of the factors behind the shift in modelling approaches which increased the importance of farm-based policy outcomes rather than representative findings.

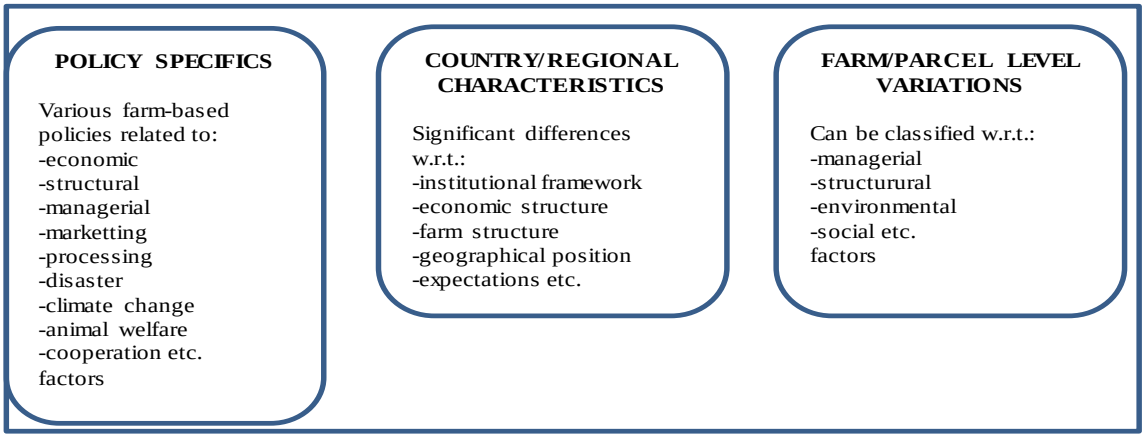

Figure 2- Factors that Led Modellers towards the Agent-Based Approach

Use of agent-based models for agricultural policy analyses is quite new and number of studies is increasing in the last decade. Modellers often choose to build these models from scratch to best fit to their modelling objectives. Hence these models may be referred to as objective-tailored. The individual elements of the approach are farms and a bottom-up strategy is followed focusing on farm behaviour. This strategy allows for modelling local and global properties by using multiple levels of hierarchical organization to represent for example villages besides the households (Kremmydas 2012; Axelrod & Tesfatsion 2012).

Therefore, probably the most striking feature of the approach appears as its capacity to model farm heterogeneity and farm interactions. The heterogeneity might be sourced by demographic characteristics of the farm, social environment of the farmer, ownership and managerial type of the farm, farm structure and environmental/climatic/geographical conditions surrounding the farm which might affect farms' decision-making process (Kremmydas et al. 2018). This flexibility that make farm characteristics endogenous allows this approach to model human–environment interactions and land use, land cover and landscape change which might be the second and third striking features of the approach.

Billari et al. (2006) highlights four advantages of agent-based models in comparison to representative type models. First, in ABMs modelling feedback relations between farms are relatively easy. Second, risk behaviour of the agents can be modelled and third, not fully rational farm behaviour can be modelled. Finally, constructing and solving problems non-tractable by non-linear systems and/or systems with a large number of interacting agents is possible. Axtell (2000) introduces a fifth advantage which is the capacity of ABMs in modelling problems far from any type of equilibrium; time, space and social networks.

Besides these advantages ABMs have some disadvantages as well. Robustness of the ABMs is weak compared to conventional mathematical models as initial conditions of the simulation are highly decisive on the solutions. The "black box" criticism arises for ABMs as well, referring to the difficulty in representing the assumptions and algorithms related to the modelling in a standardized and comprehensible manner (Kremmydas 2012). Finally, the data requirement and consistency of the required data for linking human-environment/climate-farm problem might be quite demanding.

8. A Comparison among ABMs with respect to their Modelling Capacity

This review focuses on how certain characteristics of agricultural farm holdings differ and are incorporated in agent-based models as farm holdings are the main agent/subject of the agricultural sector and as modelling the decision-making process of the agents is the main aim. Several criteria have been identified as keys to compare various agent-based models and these criteria are demonstrated with the help of a figure that centres on the farm.

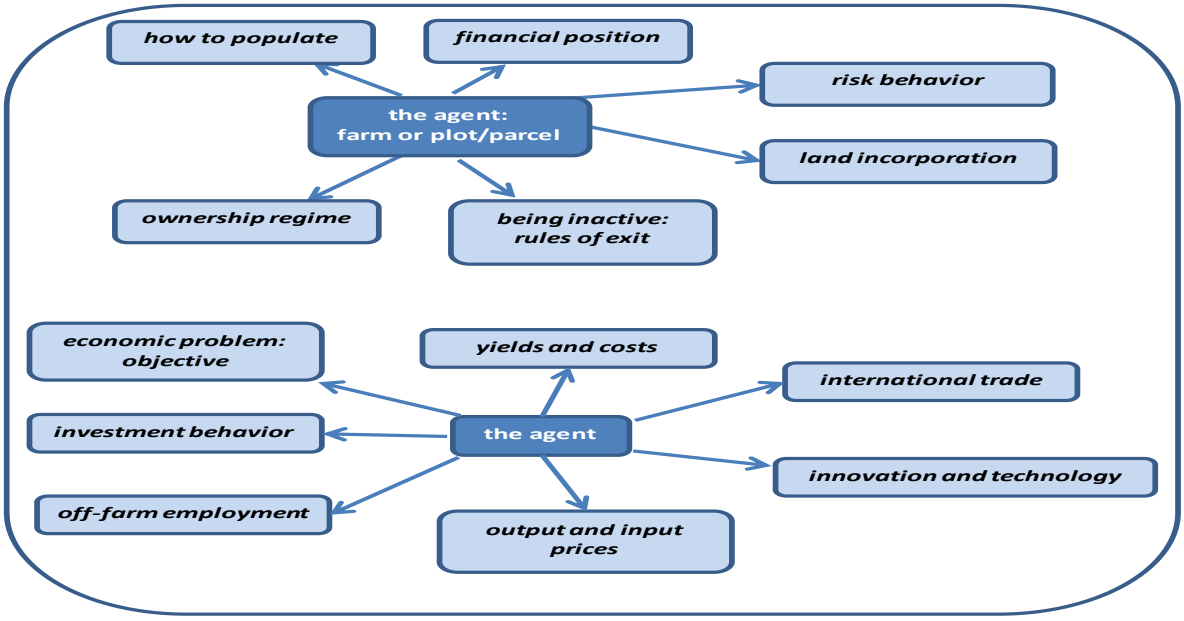

Figure 3- Comparison Criteria

The agent: farm or plot/parcel. A plot/parcel might be composed of more than one soil type and they might be exposed to different biophysical conditions. Therefore, if plot/parcel is taken as the main modelling unit (agent); geographical, climatic and biophysical conditions can be better reflected in the model whereas if farm is the agent, modelling exercise can turn into a real challenge as farms are composed of more than one plot/parcel. On the other hand, a farm (and farmer) is faced with certain economic, demographic and social conditions, institutional constraints and policies. Therefore, if the farm is the agent; then managerial, economic, social, demographic conditions can be better reflected in the model whereas if plot/parcel is the agent, incorporation of those conditions could be very difficult or impossible.

Farm ownership regime. The farm can be owned and used by the owner/farmer or might be fully or partly rented out for other farmers due to certain economic, financial, institutional and demographic factors and therefore might go to downsizing. Similarly, a farm owner or an off-farm business may rent from other farmers as well, under certain conditions to upsize the owned or non-owned agricultural land. Setting and modelling the up- and down-sizing rules is a distinguishing feature among ABMs.

Existence of inactive farms and rules of exit. ABM platforms might allow mobility of financial and productive resources between farm and off-farm opportunities. The conditions that lead to this resource reallocation might be either due to financial/economic reasons or demographic conditions such as nonexistence of successors or both. In other words, how to allow active/inactive farms to become inactive/farms is an important question. In addition, related to this, how the fallow, set-aside and idle land is handled also a notable point as “land” is the main productive factor.

Incorporation of land market. Having endogenous land market raises various questions. The models might or might not allow for renting/leasing behaviour or selling/buying or both. For each activity institutional and economic rules have to be set and integrated to the modelling algorithms. These rules might include neighbourhood and tenant rights/priorities, physical distance, profitability and regulations related to trade agricultural land. Both activities can operate through auctions and/or endogenous land prices could be determined algebraically solving land demand and supply equilibrium. Having endogenous land market is also important to model interactions among farms.

Populating with agents. Populating the agents can be achieved through real, virtual or synthetic methods. A synthetic farm is retrieved through using farm-specific databases. Therefore, each farm type (by characteristics) represented in the database can be used by weighting it in relation to the territory it belongs. Real farm information/data can also be used in ABMs. However, based on availability of the farm characteristics, the heterogeneity might turn into a real challenge in modelling farm behaviour. Populating agents by real or synthetic methods might become an important decision problem depending on whether the land data belongs to plots/parcels or farms. Virtual farms are obtained from real farms (over virtual regions) and this might help to reduce the heterogeneity problem observed in modelling farm behaviour with real farm data.

Financial position of the farm. Modelling farm management is quite significant in determining farms’ decision towards continuing/leaving farm activity. Setting financial rules for short- and long-run existence is not only about defining profitability/bankruptcy but also about how to model it in a dynamic fashion by allowing investment and borrowing from finance

institutions. The other alternative is apparently modelling farm only by cost/profit accounting which might be a short-sighted decision. On the other hand, modelling financial position of the farm might be quite difficult if the modelling entity is the plot/parcel rather than the farm.

Risk behaviour of the farm. Risks can be defined in terms of various economic, social and environmental conditions. However, in most of the times risks are reflected through their direct and indirect impacts on agricultural markets and farm management. One option to model risk is integrating it through price determination process which represents market risks for farmers. The other is integrating it through financial disposition of the farm which represents risks involved in farm management problem.

Economic problem of the farm. The main economic problem of the farm can be modelled depending on how the farm behaviour is set up in the research context. In most cases the ABMs use cost minimization and/or profit maximization as the main objective function to solve. However, in some models, maximization of farmers' utility and/or income may constitute the main problem.

Investment behaviour of the farm. Explicit modelling of investment is a distinguishing feature among ABMs. Whether an ABM allows for agricultural and/or non-agricultural investment behaviour actually is quite decisive on farms' short- and long-run financial position and profitability and it is also a part of farms' current production problem. This fact also affects farms' current resource use and cost structure.

Off-farm employment. Off-farm employment opportunity may become important in two different contexts and based on how the ABMs approach to this possibility creates the difference among ABMs. Firstly, if the main problem of the farm is income maximization then preferably modelling off-farm employment opportunities for the household members should be allowed in the ABM. Farmer's utility maximization problem also may take into account the off-farm incomes. Secondly, off-farm employment opportunities may trigger farms to exit from agricultural activity depending on the alternative income.

Incorporation of international trade. Majority of the ABMs do not model international trade endogenously. Therefore, exports and imports become exogenous to the model, if these are to be used for accounting aggregate excess supply and demand. In some ABMs telecoupling (Millington et al. 2017) methodology is employed to make international trade endogenous which is actually a hybrid approach. With this methodology exports and imports can be modelled explicitly but at aggregate levels and depending on the importance and specifics of the products, a net trade approach or bilateral-Armington approach can be adopted.

Output and input prices. Output and input markets can become totally or partially endogenous in the ABMs. In the output markets, in most cases the supply side is endogenous and demand side is exogenous to the system. If this is the approach, output prices are formulated as a function of some margins and policy parameters. If both demand and supply side are endogenous then prices are solved as an outcome of equilibrium condition. However, finding equilibrium price at farm level is not practical and therefore obtaining market or aggregate level equilibrium prices is more preferable. Another option to find output prices could be as outcome of optimization problem which gives shadow prices. In this case the convergence/divergence between shadow and actual market prices have to observed before using those. In some models, prices are fully exogenous. Input markets cover all chemicals, feeds, seeds, manure, mechanization, irrigation, land and labour. The land is handled in land market and explained separately in this paper. For labour, decision to assume exogenous labour supply is given depending on the level of unemployment, labour market regulations such as minimum wage. Otherwise both labour demand and supply can be endogenous in the system. Manure (To tackle with climate change the CAP of the EU regulates manure amount per hectare with a maximum limit which in return becomes a factor that may trigger land demand. Therefore, the modelling platforms' capability to model the relationship between land demand and manure regulation becomes a distinguishing factor) is obtained as a by-product in most models which focus both on livestock and crops. In some cases, manure is both constraint on objective function and cost in the profit function. Modelling of all types of chemicals, feeds and seeds are open to the possible options explained for output markets. Therefore, obtaining shadow prices for all inputs including labour could be an option. Mechanization and irrigation are actually part of the production technology and in most cases, these are incorporated by constant parameters. We need to mention that mechanization in some model is also a part of investment.

In addition to the above modelling features there are some other specifics that distinguish ABMs from each other. The regional focus and agricultural content are two of those specifics. Some ABMs cover forestry products besides crop and livestock production activities and all these activities are part of the decision process modelled in the optimization function. Related to models' agricultural coverage, some ABMs allow for mixed activities at farm (agent) base, while in some other farms allow for single crop only. How to incorporate innovation and technology is another distinguishing feature and, in most cases, these are introduced as a simplifying feature of mixed integer programming used to solve optimization problem. Otherwise, no innovation and fixed technology are assumed. Policy modelling capacity is another factor that creates the difference among ABMs. Some models are tailored for analysing specific policy instruments. However, the emergence of agriculture (policy) focused ABMs is actually triggered by the Second Pillar of the CAP particularly as farm-based policies in various contexts and farm-based outcomes gain importance. One last feature that distinguishes ABM platforms is about how yields and costs are incorporated. Both can be fixed or variable, but the decision is also related to how innovation and technology are incorporated and whether

input markets are endogenous or exogenous to the system. In addition, the decision on modelling unit (plot/parcel or farm) might also affect the approach to handle costs and yield. However, it should be kept in mind that using ABM approach at the first place is about modelling farm heterogeneity which might be an outcome of various economic, social, demographic and farm structural characteristics that include changing yield and cost structure.

Next section reviews 10 selected ABM modelling platforms. The content of the review depends on available documented and published material. Therefore, the review is carried out by focusing on the platform-specific features/information that could be found for majority of the ABMs under consideration. These features include main decision rule of the agents, whether the platforms allow for farm exit and rules of exit, how they approach to land market, possibility of the off-farm employment and determination of output and input prices (see Table 2). However, in addition to these features that are common to most of the found model documentations, some other model-specific features are also reviewed. The policy modelling capacity and/or policy instruments covered in the selected ABMs are not given as their "modelling procedures" in most of the cases are implicit.

In the literature there are some agent-based models which put particular focus on modelling climate change, environmental problems, water use or sometimes some social aspects such as migration. Reviewing these modelling platforms is not the priority in this paper. In fact, in the selected ABM platforms in this review, the main focus is the agricultural sector. Similarly, some studies use agent-based approach but at some extent these platforms introduce "a representative behaviour" such as at regional (Johnson et al. 2008), activity (Schmid & Sinabell 2006), farm level (Jayet et al. 2007), farm typology (Louhichi et al. 2010) etc. levels. These studies are also excluded from the review in this paper. Hybrid models which bring modelling platforms of different disciplines together such as bio-economic, bio-physical models are not also included for two reasons. First, sometimes these definitions are not definitive enough to pinpoint the utilized approaches in different components of the platform. Second, what is hybrid or not is actually a question itself.

Table 2- Review Criteria: Distinguishing Features of Selected Agent-based Modelling Platforms*

Modelling Platforms	*Modelling unit (agent); farm or plot/parcel*	*Decision rule*	*Exit; rules of exit*	*Labour market; off-farm employment*	*Output and input prices; expectations*
AGRIPOLIS	Farm	Household income max.	Allowed, financial/economic age	Endogenous; allowed	Endogenous; adaptive; agent level
REGMAS	Farm	Household income max.	Allowed, financial/economic	Endogenous; allowed	Exogenous
MP-MAS	Farm	Household income max.	Allowed, financial/economic age	Endogenous; not allowed	Exogenous
SWISSLAND	Farm	Household income max.	Allowed, age	Endogenous; allowed	Endogenous; adaptive; agent level
ADAM	Parcel	Profit max. over land allocation	Allowed, age	Exogenous; not allowed	Exogenous
LARMA	Farm	Profit max. over land allocation	Allowed, financial/economic	Exogenous; not allowed	Exogenous
PALM	Farm	Profit max. over land allocation.	Not allowed	Exogenous; not allowed	Endogenous
BAZZANA & Zhang (2022)	Farm	Maximizing farmer well-being over food security	Not allowed	Endogenous; allowed	Endogenous; activity level
MAES & PASSEL (2014)	Farm	Profit max.	Allowed, age	Exogenous	Exogenous
GLOBIOM	Farm	Profit max. over land allocation	Not allowed	Not allowed	Endogenous; activity level

8.1. Decision rules of the agents

The decision rules in AGRIPOLIS, REGMAS, MP-MAS and SWISSLAND modelling platforms are quite similar to each other. In all these platforms the agent is farm and basing on neoclassical production theory each farm-family household is assumed to maximize her income. Income is obtained as a combination of production activities and investment choice, given with respect to a set of resource constraints which means the maximized income is actually gained by family members both from on- and off-farm sources. Mixed-integer programming is used to formulate the above-mentioned behavioural model and optimization problem bring together farm factor endowments, production activities, investment possibilities, and other restrictions and circumstances. While in REGMAS the maximization problem is solved to generate results over multiple years, in others the solution is given for the production period/financial year. In MP-MAS the objective function can also be defined as multi-dimensional utility function that includes income and consumption.

In ADAM, LARMA, PALM and GLOBIOM modelling platforms, the main driver behind optimization problem is the change in land use and land allocation. Farms, as the agents, maximize their profit under certain internal (farm-based) and external (economic, social, environmental, political) properties. The distinguishing feature of PALM and LARMA is that the former has a biophysical component originally designed to simulate the flow of resources in rural communities while the latter has a market component that relies on neoclassical assumptions. The main feature of ADAM is that the solution of the model decides whether a new farm will be created, whether a farmer continues, stops its activities, or takes over an individual parcel or an entire farm. In GLOBIOM the objective is to allocate the land among agricultural and forest products to maximize the sum of producer and consumer surplus with respect to above-mentioned properties, as well as demand and technological conditions. A difference from all the above platforms is that GLOBIOM is recursive dynamic and creates projections for future.

Maes & Passel's (2014) modelling platform takes a different approach than the aforementioned ones by using three distinct objective functions. Agents make decisions based on the level of financial risk they are willing to accept and the availability of financing in order to maximise the farm's profit. The first objective function is profit maximisation, and like the previous platforms, it is confined by the agent's ability to choose among alternatives and the availability of loans. Maximising the total value of the farm, including its liquid and fixed assets as well as its agricultural land, is the second objective function, which has a longer-term focus. These farmers aim to establish a farm that will consistently provide sizable annual earnings. The third criterion takes into account the perfect layout of a farm. When compared to other platforms, Bazzana & Zhang (2022) takes a novel strategy, prioritising the food security of farmers as a key indicator of their success.

8.2. Farm exit and rules of exit

The agent in AGRIPOLIS and REGMAS decides whether to exit or stay in the sector based on expected returns for the next year. If the farm agent’s equity capital is zero (the farm is illiquid) or if off-farm income of the farm-owned production factors (land, family labour, and working capital) is higher than farm income then it becomes rational for the agent to exit. In AGRIPOLIS, exit decision can be also given if the farm agent has reached a certain age and there are no successors to take over. However, even if there are successors, their off-farm generated income should be lower than farm income otherwise they are assumed not to take over. Opportunity costs of farm labour are quite decisive. In MP-MAS the agent exits if the bankruptcy cannot be avoided. Based on the physical and economic outcomes of the production/investment decisions given in the first step, the agent either sell assets to retain solvency and continue farming or leaves the agricultural sector. Successors’ take over in MP-MAS in case household members die, retire or give birth is a desired feature. The agent is willing to forgo own-income if a major investment or expansion of the farm is necessary to employ their successors. In SWISSLAND platform, agents reaching a certain age threshold (qualifying to get direct income support) leave the farm business to potential successors (if there are) and the successors take over if the farm income is above the average level of income in the region. In ADAM, a similar process to SWISSLAND is implemented except that no age threshold is used and farm profitability is the key criteria. The exit/stay decision of the agent in LARMA platform is given based on whether the level of calculated working capital in each production cycle covers implantation and rental costs. In Maes & Passel (2014), succession to family members is a crucial step even if the agent evolves to an elderly farm without much growth, new investment, high efficiency or new innovations. The activity only stops when the owner passes away.

8.3. Off-farm employment

In AGRIPOLIS and SWISSLAND platforms, the labour market is modelled endogenously (or it is partly endogenous) and both allows for off-farm employment. However, the approaches used to model labour market in each platform is quite different. In AGRIPOLIS, labour supply is composed of three different types. First group of labour is sourced by farms (farm family labour), the second group can be hired for agricultural purposes on fixed term contracts or on hourly basis. The last group is composed of the labour offered by the farm to market for employment either in non-professional agriculture in off-farm opportunities. Total labour supply is determined in the mixed-integer programme as variable and fixed labour activities. The SWISSLAND platform forecasts the use of family labour, external labour and off-farm work by using a two-phase procedure. The first phase estimates the agents’ most likely labour-adjustment strategies by using Bayesian Network and the second phase determines the optimal labour-input strategies by using cluster analysis. The results of cluster analysis are used to set up the Bayesian Network and

parameterise all observed labour-adjustment strategies in the single-farm optimisation model. In Maes & Passel (2014) labour market is totally exogenous. In Bazzana & Zhang (2022) farms may hire outside workers if the optimal amount of labour required is higher than the farm family labour but the model allows this only if there is enough available agricultural income. The model allows for the opposite case as well where the household provides labour force to other farms to generate income. The wage level in the economy is assumed to be equal across farmers and labour can be hired within the village border.

8.4. Land market

In AGRIPOLIS platform land owned by farm agent is either landowners or external, non-farming landowners where the latter are not explicitly modelled but they can rent their land to farm agents. Land sales/purchases is not allowed. Land is distinguished as arable land, grassland and non-agricultural land and in each group quality is assumed to be homogeneous. All types are also assumed to be either managed land or abandoned land. All managed land is either owned or rented by farm agents. Bilateral interaction among agents in the land market is not allowed and the interaction occurs through sequential auctions in land market. Rental land is sourced either by agents withdrawn from the sector or by terminated rental contracts or both. A two-step auction process is modelled. Once free plots are released first, each farm agent produces a bid for a particular plot of land, basing the bid on marginal income from additional plot of land (shadow price for land, the number of adjacent farm plots, and the distance-dependent transportation costs between the farmstead and the plot). Second, the highest bidder agent is given the plot by the auctioneer. The space in AGRIPOLIS is represented by a set of equally sized cells/plots differentiated with respect to type of soil, type of ownership, state of the plot, size of the plot and transportation costs to the respective farm managing the plot.

In contrast to AGRIPOLIS, where space is represented by plots that are modelled with respect to soil type, in REGMAS, space is represented by plots that are modelled explicitly (using real land-use information). While the land market mechanism (auction) allocates vacant lots to agents, the REGMAS platform does not provide land sales/purchases or bilateral farm agent interaction in the land market. To ensure that all fixed and variable transaction expenses and overhead are covered, real estate agents assign a shadow price (the optimal solution to a profit-maximizing mixed integer programme) to each available rental unit. Distance from the rentable plots is used to limit the number of bidders in REGMAS (greater transport costs mean less likely it is that a certain farm will present a winning bid-to afford a better economic performance). The property is rented to the highest bidder. The land market is managed in the MP-MAS platform in a method quite similar to that of the REGMAS. If the shadow price for land is less than the actual average land price, land sales/purchases are prohibited and a renting decision is made. The land is rented to the highest bidder, and the bidder with the lowest internal transport cost (shortest distance) wins. SWISSLAND takes a different tack by not implementing a clear land market. Land swaps between neighbouring municipalities and within established neighbourhood patterns (farm sites) are first permitted. The second phase is to place the agents at the farms within the cities. In the third stage, the land lease from the "exiting agents" to the remaining agents is modelled, parcel by parcel. If a farmer on the SWISSLAND platform does not have a clear economic heir or if a potential heir decides against taking over the farm, the farmer is free to leave the industry. A plot's income increase is a major factor in the leasing decision made by an agent. After optimising for the new land, each agent rents it out to their nearest neighbour who stands to make the most money from the change. If a plot's adjoining agents are unable to turn a profit, the scheme is abandoned.

The ADAM platform is developed to model land use change and drivers behind the change. The modelling is done at parcel level to capture farms' abandonment or growth. The change in land use can be an outcome of certain conditions. Parcels are released if no new owner can be found, because the parcel is too far away or if no successors are left. Conversion of agricultural lands to residential houses can be another case. Changing cultivated crops on arable land basing on expected yields for the area and crop prices is another factor and finally converting the land to another type of agricultural land use is set as the last condition. Priority in getting the parcels is given to farmers from the same farming type as the previous owner or to a farmer who can easily convert the parcel to a desired agricultural land use. In Maes & Passel (2014) platform, simply any agent may enter bids for either the purchase or the sale of land with a requested price and sale/purchase bids are combined in the double auction mechanism to establish a negotiated transaction price. The other modelling ABM platform that focuses on land use change is the GLOBIOM. Space in the GLOBIOM platform categorises plots/parcels into groups with similar topography. Cropland, grassland, short rotation plantations, managed forests, unmanaged forests, and other natural vegetation land are the six types of land cover (the other three types of land cover (other agricultural land, wetlands, and not relevant) are held constant at their initial level and are not modelled). The predicted profitability (conversion cost is also considered in producer optimisation behaviour) drives the platform's modelling of land conversion among the first four land cover types. There are constraints on land conversion, such as the land's biophysical appropriateness and its production potential. At the local level, land use change is analysed on a per-hectare basis according to a conversion ruled by a matrix of land use conversion options (region-specific) between land use types and associated conversion costs (Havlik et al. 2018).

The LARMA platform is specifically a land rental market model -without allowing for sales/purchases- with a highly unique endogenous formation of land rental price. There are two agent types involved in agricultural activities: farmers who either operate owned and/or leased farms, and who rent out their land. The agents' land allocation strategies, risk aversion behaviour and financial characteristics differ among them. As similar to other platforms no bilateral interaction among agents take place rather the land market mechanism -called the manager- does the required calculations and re-allocation. The platform determines land prices through a series of model steps. First the agent-farmer updates the area that is needed (whether the farmer maintain

or expand or release some/all of the previously farmed area) basing on expected status of climate conditions, output prices, input costs. This first step is actually identifying the demand for and supply of land in the market. In the second step prices that agents are willing to pay (expanding land) or get for land (releasing land) are endogenously and dynamically determined depending on agents' working capital and risk behaviour. Finally, a market clearing price is calculated by considering the willingness to pay (WTP) and willingness to accept (WTA) prices.

Table 3- Land Market Specifics of Selected Agent-based Modelling Platforms

	AGRIPOLIS	***REGMAS***	***MP-MAS***	***SWISSLAND***	***ADAM***	***LARMA***	***GLOBIOM***
Land cover/use change	land cover	land cover	land cover	land cover	land use	land cover	both land cover/use
Land ownership	both farmer and non-farmer land owners	farmer land owners	farmer land owners	not important	farmer land owners	farmer land owners	farmer land owners
Land sales/purchases	not allowed	not allowed	not allowed	not allowed	not allowed	not allowed	not allowed
Land renting/hiring	Allowed	allowed	allowed	allowed	allowed	allowed	not allowed
Land type/quality	arable, grassland, non-agri. land / homogenous in each group	mixed/heterogeneous in each group	mixed/heterogeneous in each group	product based/both organic and conventional	barns, grassland, greenhouses, permanent crops, or arable land	field crops/ homogeneous	cropland, grassland, short rotation plantation, managed and unmanaged forests, natural vegetation, others
Bilateral interaction/Land price	only through 2 step auction/land shadow price	only through auction; bidders are restricted by distance/land shadow price	only through auction; bidders are restricted by distance/land shadow price	neighbour with max. profit can rent land	priority given to same or similar farmer type	endogenous land market through WTP and WTA mechanism	not allowed
Space representation/quality	equal sized plots/heterogeneous	equal sized plots/homogenous	equal sized plots/homogenous	not important	unequal sized parcels/heterogeneous	unequal sized/ homogeneous	equal sized plots/heterogeneous
Exit/rules of exit	allowed/financial-economic, age	allowed/financial-economic	allowed/financial-economic, age	allowed/age	allowed/age	allowed/financial-economic	not allowed

8.5. Output and input prices

In ABM platforms both the current and future prices are in the focus of interest. While current prices can be determined endogenously or exogenously, future prices are formulated as a result of some sort of expectation function. In AGRIPOLIS for example, markets for products, capital, and labour, are coordinated via a price function with an exogenously given price elasticity and a price trend. The optimization problem in the platform produces the vector of shadow prices which are interpreted as the actual prices. But for future the prices are expected to stay constant. Therefore, dynamic effects of market and demand developments are neglected. The agents follow adaptive expectations (myopic behaviour) while planning decisions. They foresee all prices as a weighted geometric average of actual and expected prices. In SWISSLAND platform domestic prices are determined endogenously by interaction of demand and supply at activity level and expectations are derived from the previous year's prices. Domestic prices are specified as a function of world prices, exchange rates, transport costs, and country-specific policies that affect prices. Each year, prices are multiplied by the previous year's annual relative price trends, which are calculated endogenously in the demand module. Input prices, except for feed, are exogenous and are based on historic trends. In REGMAS, MP-MAS and Maes & Passel (2014) platforms current prices are exogenous and some expectation formula is used for getting future prices in REGMAS and MP-MAS platforms. Both in Bazzana & Zhang (2022) and GLOBIOM modelling platforms prices are endogenously determined for each activity level. While in the former there are price evolution coefficient that derive the current product prices, in the latter market equilibrium conditions provide the activity level prices.

Some of the more general characteristics of the above-explained platforms are briefly presented in the following paragraphs. In AGRIPOLIS agents distinguish between standard production (both livestock and crops) activities, auxiliary activities,

investment activities, and the decision to continue farming. Production factors used in activities are land, buildings, machinery, liquid capital, labour of different types and capacities. Land rental activities, production quotas, and manure disposal rights are included in the auxiliary activities. Farm agents are allowed to take long-term and/or short-term credit and unused liquid assets are invested at the assumed savings rate. Technological change is not explicitly modelled however production technologies are assumed to progress over time and with every new investment unit production costs are assumed to decrease (cost-saving technology which can only become an outcome if larger machinery and larger field sizes are combined together). Production costs are formed by expectations of agents. Agents in REGMAS are involved in operations that have both short-term (annual) costs and long-term (investment) benefits. Although investments are limited to whole numbers, a particular asset can come in a variety of sizes. This gives rise to scale-effects in the model. However, scale effects (land/farm size), investment, and technology implications can be represented in systems that use mixed integer programming. Farmers' resource endowment, activity gross margins (produced endogenously through investment decisions, newly rented plots, or exogenously through market price changes and policy support), and other environmental factors are the primary focus of REGMAS's modelling efforts.

Similar to REGMAS, in MP-MAS platform main concern is to understand how agricultural technology, market dynamics, environmental change and policy intervention affects a heterogeneous population of farm households and the related agro-ecological resources. The platform combines biophysical production functions for irrigation and fertilization with constrained optimization models. Agents are engaged with crop production, grassland use, animal production and biogas production. The model has a long-term perspective and dynamic approach under which the decisions are given by considering sunk costs and lack of liquidity that might create possibility for farmers to trade land or give up farming. The SWISSLAND utilizes a recursive dynamic partial-equilibrium, multiple-commodity approach to create solutions for 10 to 15 years. Agents are involved mostly with livestock activities but products are assumed to be homogenous among agents/farms although the heterogeneity is introduced by farm characteristics. The platform solves reduced-form behavioural equations for production, consumption, and trade.

Internal and external factors are modelled in ADAM to predict how agents/farms will make decisions on changes to agricultural land use. Each farm consists of a number of individual parcels, and each of those farms focuses on a single primary farming method. Agents in PALM consider ecological, social, and economic factors while making land-use decisions. The household agents' choices lead to actions, which may alter water, carbon, and nitrogen fluxes over the landscape. There is also a physiological aspect to it. Different farmers have different responses because of the consistent decision-making technique used in the multidimensional preference space. The model presented in Bazzana & Zhang (2022) posits that agents/farmers are bounded rational and follow simple rules of behaviour due to the imperfect and asymmetric information context in which they operate. The disparities in human, physical, and social capital are the root cause of this information gap. With no input substitution possibilities and the ability to employ irrigation, a production function of the Leontief type is developed.

In specifically, Maes & Passel (2014) model the effects of structural change on agricultural agents' decisions to switch between different types of animal stocks, investments, and land. Single-farm and multi-farm operations are also supported by the modelling framework. Exogenous models are used for inputs like capital, labour, fertilisers, investments, and output markets, whereas inputs like land, manure, and animals are modelled endogenously. Live animal markets factor in transactions with processing plants. The costs are the result of econometric estimation, with the current state of technology held constant. Land, livestock, and agricultural investments are eligible for bank financing. GLOBIOM is a partial-equilibrium platform that focuses on land-based sectors including agriculture (both crops and livestock), forestry, biofuels and timber markets. The platform analyses the impacts of climate change mitigation and adaptation policies. The model is solved recursively dynamic and can provide projections up to 2100. Parameterization of the alternative Leontief type production functions in GLOBIOM is partially carried out by biophysical models integrated to the platform. In addition, GLOBIOM endogenously represents mitigation technologies including technological and structural mitigation options. The platform also models bilateral trade flows between individual regions assuming all products are homogenous across regions.

9. Conclusions

There is always a trade-off when it comes to choosing a method in impact analysis. The advantages of the chosen method often become the disadvantages of the non-chosen ones and the opposite is also true. Although these facts are valid, we can still say that recently there has been shift from the systems approach (as defined in the above) to the agent-based approach in impact analysis. We can talk about four major factors driving this shift as:

1. Policies implemented under the CAP have increasingly focused on farm and rural development in Pillar II, and the heterogeneous nature of farms and the economic interactions among farms have become more important.
2. Based on the first factor mentioned above, the farm-based policy outcomes rather than sector/country (region)-wide effects become more important. A fact that supports this is that the changing economic and institutional structures of the countries differentiate the responses on the basis of the farm.
3. In general, the environmental and sustainability (in the environmental, social and economic context) implications of policies have become more important. These implications also vary depending on the location of the farms rather than the countries.

4. Advance in data (i.e., geo-referenced, CORINE) and analysis tools (statistics and machine learning) can be considered another driving factors to shift modelling approach.

Challenging Issues

A significant challenge for agricultural/rural policy impact assessment studies/methodologies arises in determining the analysis level. The assessment platform preferably should represent the heterogeneity of the farms and consider the economic interactions among them while both input and output market adjustments are allowed in the same platform. The challenge here is that modelling farm behaviour does not always necessitate endogenous output/input markets and trying to achieve both could be cumbersome.

Another challenge could be the time horizon adopted in the analysis platforms which actually determines the "mathematical formulation of the farm problem". In some cases a short-term perspective is adopted and farm behaviour is optimized with respect to economic conditions, whereas the platform might embrace a long-term perspective in which the optimization is based on changing financial position of the farm.

Third challenge is the inclusion of environmental factors/components into the modelling platforms. Environmental factors can be examined in a very wide scope (soil, water, biodiversity, landscape, air, climate change etc.) and this scope may differ according to country/region/farm location. At this stage excluding environmental factors from the modelling platforms is out of discussion since agricultural sustainability is one of the main objectives of the changing CAP. It is one problem to find the necessary data at the analysis level, and is another problem to parameterize and calibrate the modelling platforms with these environmental modules.

Finally, the adjustment between primary and secondary data (spatial inconsistency); between the level of social, economic and environmental data is another challenge. As the modelling platforms is expanded with various environmental components and with other output and input use data, adjustment problems become costly in terms of time and effort. The increasing availability of spatial data seems to be a solution however it calls for big data tools. Advance in "machine learning technic" including its integration with AI will facilitate to finding solution to calibration issues in ABM.

This literature review identifies the trade-off elements that may arise when using the agent-based modelling approach for impact analysis of agricultural and rural development policies. Based on the information revealed by the survey, a few directions can be made for researchers working on the subject. In this type of analyses, it is necessary to determine what the research question addresses and who are the end-users. The answer to these questions would determine the impact measurement scale of the analysis and hence will reveal if there is a need for an agent-based model or not. On the other hand, it is also a priority to correctly identify the question to which the answer is sought, and thus to correctly identify the explicit and implicit objectives of the changing policies. The most comprehensive and detailed modelling and analysis does not necessarily mean that it is the best approach. All or most aspects of an analysis can be handled in a single modelling platform such as with an integrated assessment platforms that integrate several modules. However, complexity always comes with various technical difficulties. An alternative approach would be to search for answers to the questions both in a highly disaggregated structure, such as agent-based models, and in an aggregated structure with representative characteristics. Then, analysing the consistency between the findings of the two approaches would be a rather powerful and relatively technically easier problem to solve.

References

Axelrod R & Tesfatsion L (2010). On-line guide for newcomers to agent-based modelling in the social sciences. Handbook of Computational Economics 2.

Axtell R L (2000). Why agents? On the varied motivations for agents in the social sciences. In Proceedings of the Workshop on Agent Simulation: Applications, Models, and Tools. Argonne, Illinois.: Argonne National Laboratory

Bazzana D, Foltz & Zhang Y (2022). Impact of climate smart agriculture on food security: an agent-based analysis. Food Policy, 111, 102304.

Billari F C, Fent T, Prskawetz A & Scheffran J (Eds.). (2006). Agent-based computational modelling: applications in demography, social, economic and environmental sciences. Taylor & Francis

Emmerson M, Morales M B, Oñate .J, Batáry P, Berendse F, Liira J, Aavik T, Guerrero I, Bommarco R, Eggers S, Pärt T, Tscharntke T, Weisser W, Clement L & Bengtsson J (2016): How agricultural intensification affects biodiversity and ecosystem services. Advances in Ecological Research 55: 43-97

European Commission (1988). The future of rural society: Commission communication transmitted to the Council and to the European Parliament. Office for Official Publications of the European Communities. COM (88): 501. Available at http://aei.pitt.edu/5214/1/5214.pdf (accessed June 2021).

European Commission (2023). The Cork Declaration - A Living Countryside. Statement by the European Commission at the European Conference on Rural Development, , Cork. Available at http://www.aughty.org/pdf/cork_declar.pdf (accessed June 2021).

European Union (EU) (2016). Cork 2.0 Declaration: A better life in rural areas. Available at https://enrd.ec.europa.eu/sites/default/files/cork-declaration_en.pdf (accessed June 2021)

FAO/WB (2016). The evolution and the impact of EU regional and rural policy. Working Paper. Available at http://www.fao.org/3/aj280e/aj280e.pdf (accessed June 2021).

Havlik P, Valin H, Mosnier A, Frank S, Lauri P, Leclère D, Palazzo A, Batka M, Boere E, Brouwer A, Deppermann A, Ermolieva T, Forsell N, di Fulvio F & Obersteiner M. (2018). GLOBIOM documentation. International Institute for Applied Systems Analysis (IIASA). Laxenburg, Austria

Jayet P A, Debove E, Kleinhanss W, Küpker B, Júdez L & Xepapadeas A (2007). Land market & Genedec. Presentation at DG Agriculture in Brussels, March 5th. Available at https://www.researchgate.net/profile/Pierre-Alain-Jayet/publication/266469538_Land_market_Genedec/links/55f04c3208ae199d47c1fcb6/Land-market-Genedec.pdf (accessed May 2021).

Johnson T G, Bryden J M, Refsgaard K & Alva-Lizarraga S. (2008). A system dynamics model of agriculture and rural development: The TOPMARD core model (No. 692-2016-47419). Paper prepared for presentation at the 107 the EAAE Seminar, Sevilla, Spain, January 29th -February 1st. Available at https://ageconsearch.umn.edu/record/6497/ (accessed May 2021).

Kremmydas D, Athanasiadis I N & Rozakis S (2018): A review of agent-based modeling for agricultural policy evaluation. Agricultural Systems, 164: 95-106.

Kremmydas D (2012). Agent-based modelling for agricultural policy evaluation: A review, AUA Working Paper Series No.2012-3, December. Available at https://www.researchgate.net/profile/DimitriosKremmydas/publication/261552249_Agent_based_modeling_for_agricultural_policy_evaluation_A_review/links/00b495349a4839cd48000000/Agent-based-modeling-for-agricultural-policy-evaluation-A-review.pdf (accessed Nov 2021)

Louhichi K, Kanellopoulos A, Janssen S, Flichman G, Blanco M, Hengsdijk H, Heckelei T, Berentsen P, Lansink A O & van Ittersum M (2010). FSSIM, a bio-economic farm model for simulating the response of EU farming systems to agricultural and environmental policies. Agricultural Systems 103(8): 585-597

Maes D & van Passel S (2014). An empirical economic model to reveal behaviour characteristics driving the evolution of agriculture in Belgium in Miguel, Amblard, Barceló & Madella (eds.) Advances in Computational Social Science and Social Simulation Barcelona: Autònoma University of Barcelona

Millington J D A, Xiong H, Peterson S & Woods J (2017). Integrating modelling approaches for understanding telecoupling: global food trade and local land use. Land, 6: 56. Available at https://www.mdpi.com/2073-445X/6/3/56/htm (accessed July 2021).

Rizojewa-Sileva A, Pilvere I & Zeverte-Rivza S (2018). Agriculture modelling in the European Union. In Proceedings of the International Scientific Conference "Economic Sciences for Agribusiness and Rural Economy" (No. 2). Warsaw, 7–8 June, pp. 45–50. Available at https://js.wne.sggw.pl/index.php/esare/article/view/1493 (accessed May 2021)

Schmid E & Sinabell F (2006). Alternative implementations of the single farm payment distributional consequences for Austria. Discussion Paper DP-17. Institut für nachhaltige Wirtschaftsentwicklung. Availabl at https://www.econstor.eu/bitstream/10419/236557/1/dp17-2006.pdf (accessed April 2021)

Troost C & Berger T (2015). Dealing with uncertainty in agent-based simulation: farm level modeling of adaptation to climate change in Southwest Germany. *American Journal of Agricultural Economics* 97(3):833–854

https://ec.europa.eu/jrc/en/research-topic/rural-development

https://www.europarl.europa.eu/factsheets/en/sheet/110/second-pillar-of-the-cap-rural-development-policy

https://ec.europa.eu/info/food-farming-fisheries/key-policies/common-agricultural-policy/rural-development_en.

https://ec.europa.eu/info/food-farming-fisheries/key-policies/common-agricultural-policy/cap-glance_en.

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Agricultural Output and Economic Growth Nexus: A VECM Approach on Bangladesh

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ABSTRACT
Agriculture is the engine of an economy. In Bangladesh, 50% of the entire labor force is employed in farming, and around 87% of rural families depend on agriculture for any part of their wages. Considering the importance of the agriculture sector in Bangladesh, the study examines the nexus between agricultural output and economic growth. In the finding of this causality, the VECM test was applied, and the long-run relationship between variables was found, where the rate of restoring the disequilibrium into equilibrium was 66.4%. The research applies the impulse response function and variance decomposition, where, in both cases, the result implies that the agricultural output is much more significant in economic growth than industrial output, meaning that to be a sustainable economy, the agriculture sector cannot be ignored. The study also provides insights to the policymakers that the agriculture sector should be given much more priority in terms of budget, and the academicians should do more research to develop sustainable agro-based products.

Keywords: Agriculture, Industrial Output, GDP, VECM, Impulse Response Function, Variance Decomposition

1. Introduction

Agriculture is the center area for the economy of Bangladesh since its independence and as yet contributing around 13% to GDP. Other than giving work to 40.62 percent of the workforce, this area gives convenience 62% labor of the country, and 84 percent of the inhabitants in Bangladesh living in country regions straightforwardly or by implication relies on agribusiness for their business. It is one of the major sources of business, work, and food security for most local individuals. On the other hand, industry is also a major parts of economic development (Lewis 1954). Raw materials for industries are coming from agricultural sector which is undeniable (Johnston & Mellor 1961). It likewise gives crude material to industry and adds to nation's prices. So any technique change for agricultural area will influence the economy and a huge segment of population in the nation (Alam 2008). In any case, because of the fast turn of industrialization, transformation of a country, the agriculture area has been continuously disregarded. All things considered, understanding the part of agriculture and its linkages to economic development is significant.

As stated by development economists, improved agricultural productivity is the key to an effective national strategy (Lewis 1954; Mellor 1976; Nurkse 1953; Rostow 1990). Lewis (1954) posits that industrialization is linked to agricultural growth and productivity. Johnston & Mellor (1961) and Mellor (1976) believes that agriculture is essential to industrial and domestic growth. This has to do with food production, purchasing power, labor, and the multiplier effect on the countryside. According to Adelman (1984), 'agricultural demand-led' industrialization is a viable alternative to other models of industrialization.

During recent years, Bangladesh's GDP has exhibited a substantial upward trajectory, yet the agricultural sector's growth has decelerated, marking a decline from an average growth rate of 9.21% to 3.92% per annum from 1990 to 2019. This shift indicates a gradual transition from an agrarian economy towards one where the industrial and service sectors play dominant roles. Despite this transition, the importance of agriculture in economic stability and poverty reduction remains undiminished, thanks to its contributions to food production and rural employment. The evolving dynamics of Bangladesh's economy, marked by significant growth in the service and industrial sectors, beckon a reassessment of agriculture's contribution to economic growth.

The primary aim of this research is to explore the relationship between agricultural output and economic growth in Bangladesh, focusing on understanding how economic growth responds to fluctuations in the agriculture sector. This understanding is crucial for identifying effective strategies to stimulate economic growth.

Specifically, the study aims to address the following objectives:

1. Evaluate the impact of agricultural output on economic growth in Bangladesh, recognizing its critical role in the nation's development.

2. Compare the influences of agricultural and industrial outputs to determine which has a more significant effect on the country's economic growth, considering the theories of 'agricultural demand-led' industrialization.

3. Examine the short-term and long-term dynamics of the variables involved, shedding light on their interplay and implications for policy formulation.

2. Literature Review

The literature indicates an intricate correlation between agricultural production and economic development, with certain studies highlighting a positive and co-integrated association, while others highlight subtleties and discrepancies in this correlation based on diverse contexts and methodology. Specifically, within the framework of Bangladesh, a developing nation, this part provides a meticulous examination of the agricultural sector in Bangladesh and its role in contributing to economic growth in a comparative scenario. The existing research gaps necessitate a fresh study to investigate the impact of agricultural output on the economic growth of Bangladesh.

Siddique & Selvanathan (2012) found that remittances have a substantial impact on economic growth in Bangladesh, highlighting their vital role in driving the economy. In their study, Nath & Mamun (2005) examined the correlation between exports and economic growth, emphasizing the significance of exports in driving economic progress in Bangladesh. Adhikary (2010) investigated the relationship between foreign direct investment (FDI), trade openness, capital formation, and economic growth rates. The study emphasized the significance of these elements in influencing the country's economic growth path. In addition, Shahbaz et al. (2014) examined the direct relationship between labour and economic growth, while Hossain & Wadood (2020) highlighted the significance of interest rate deregulation in promoting financial depth and economic growth in Bangladesh. FDI has been a central topic in studies on economic growth, with research conducted by Rajib & Rahman (2020) and Asaduzzaman (2019) emphasizing the beneficial effects of FDI on the economy of Bangladesh. In addition, Hossain et al. (2018) recognised human resource development and trade openness as crucial elements that have a favourable impact on economic growth in Bangladesh. The research conducted by Hossain & Wadood (2020) explored the capacity of tourism to stimulate economic growth and generate employment opportunities within the nation.

Agriculture plays a significant role in Bangladesh's GDP, accounting for around 18.70% during the fiscal year of 2012 to 2013 Hasan et al. (2017). Although agriculture is important, the Readymade Garment (RMG) business has emerged as a significant source of foreign currency in Bangladesh (Islam et al. 2018). Moreover, there exists a well-established mutual reliance between agriculture and other sectors in Bangladesh, wherein the industrial and construction sectors make a good contribution to agriculture (Hossain et al. 2012). The findings underscore the importance of agriculture in reducing poverty and its interconnectedness with other sectors of Bangladesh's economy.

The agriculture sector in Bangladesh is of paramount importance to the nation's economy and population. The study conducted by Rahman & Salim (2013) examined the changes in total factor productivity and the sources of growth in the agricultural sector of Bangladesh over a period of six decades. The research highlights the significant role of this sector in the overall development of the country. In addition, Ghimire et al. (2021) emphasize that Bangladesh's economy is highly reliant on agriculture, which makes a substantial contribution to both employment and the country's gross domestic product (Ghimire et al. 2021).

Agriculture continues to play a crucial role in ensuring food security and sustaining livelihoods in Bangladesh, as shown by Rezvi (2018) and Bishwajit et al. (2014). The agricultural sector remains a crucial component of the nation's economy, attracting significant focus and playing a pivotal role in supporting the population and guaranteeing food security, as highlighted by Das and Hossain (2020) and Rahman et al. (2022).

Various econometric methodologies have been used to evaluate the impact of agricultural output on economic growth in different nations. Kelikume & Nwani (2020) employed dynamic econometric tools to examine the connections between agricultural sector output and real GDP in Nigeria. Salim et al. (2019) conducted a study in Bangladesh to examine the interconnections between research and development (R&D) spending, climate change, human capital, and total factor productivity (TFP) growth in agriculture. In addition, Dey (2022) utilised many econometric tools, including the augmented

Dickey-Fuller test, Johansen cointegration test, and ordinary least squares (OLS) method, to evaluate the effects of significant crop output on the agricultural sector in Bangladesh.

In their econometric analysis, Hasanov et al. (2022) utilised Autometrics with super saturation to find the factors that contribute to agricultural growth in Azerbaijan. The study found that land, labour, and capital have a considerable positive effect on agricultural productivity in the long run. In addition, Wang et al. (2010) performed an econometric research using a model in China, indicating a favourable correlation between agricultural and economic expansion.

Ultimately, the interplay of remittances, exports, FDI, trade openness, human capital development, and interest rate policy are pivotal in driving economic growth in Bangladesh. Agriculture has a crucial role in the economic development of Bangladesh, as numerous studies have shown. However, most research in Bangladesh have not concentrated on using econometric analysis to analyse the agricultural sector in the country. Furthermore, the exploration of the roles played by the industrial and agricultural sectors in Bangladesh has not yet been undertaken in a comparable context. The primary objective of this study is to address the deficiencies in the current literature and provide policy recommendations for the agriculture sector in Bangladesh.

3. Theoretical Framework

The theoretical framework of this study on the nexus between agricultural output and economic growth in Bangladesh is anchored on several key economic theories and models. This framework seeks to integrate these theories to explore and understand the dynamics between agriculture productivity and economic development, providing a structured lens through which the research objectives can be examined.

3.1. Dual-sector model (Lewis 1954)

The dual-sector model, proposed by Arthur Lewis, suggests that the transition of labor from a traditional agricultural sector to a more productive industrial sector is essential for economic development. According to this model, surplus labor from the agricultural sector is absorbed by the industrial sector, leading to increased productivity and overall economic growth. This model underlines the significance of the agricultural sector as a foundational base for providing the initial labor force necessary for industrial growth.

3.2. The theory of agricultural demand-led industrialization (Adelman 1984)

Adelman's theory posits that the expansion of the agricultural sector can stimulate demand for industrial goods, thereby driving industrialization and economic growth. This approach suggests that improvements in agricultural productivity and income lead to increased consumption and demand for diverse products, including those produced by the industrial sector. The theory emphasizes the interdependence between the agricultural and industrial sectors and their joint role in advancing economic development.

3.3. The linkage approach (Johnston & Mellor 1961)

Johnston and Mellor highlighted the importance of linkages between agriculture and the rest of the economy. They identified both forward linkages (where agricultural outputs are used as inputs in other sectors) and backward linkages (where the growth of other sectors increases the demand for agricultural inputs). This approach suggests that the agricultural sector's growth can have a multiplier effect, stimulating economic activity across various sectors through supply and demand linkages.

4. Methodology

4.1. Test of stationarity

The time series, the statistical properties of a series of mean and time variance are known as its stationary characteristics. If both are constant, the range is considered to be stationary (i.e. there is no random walk/no unit root), otherwise the random walk/has unit root is characterized as non-stationary. Other observations are created when a set is differentiated by differentiating, such as first differentiated values, second differentiated values, and so on.

When a series is stationary at level, it is referred to be integrated at order 0 or I (0), and the first differenced stationary is referred to as integrated at order 1 or I (1). The Dickey-Fuller Generalized Least Square (DF-GLS) by Elliott et al. (1992) and Kwiatkowski-Phillips-Schmidt-Shin (KPSS) unit root test by Kwiatkowski et al. (1992) is used in this study to assess the stationarity of data series.

Dickey-Fuller test modifies by Elliot, Rothenberg and Stock known as the DF-GLS test. This unit root test is stronger than the ADF test. The function of regression is:

$\Delta X_t^d = \alpha_0 X_{t-1}^d + \alpha_1 \Delta X_{t-1}^d + \ldots\ldots + \alpha_p \Delta X_{t-p}^d + \epsilon_t$

Where; ΔX_t^d represents the detrended series. While the DF-GLS only comprise the intercept, the value of t is the same as the ADF test and its critical value is the same as in the ADF test. When DF-GLS tests have trends as well as an intercept, they are different in their distribution and their critical value is in accordance with the ERS test.

4.2. The Johansen test for cointegration estimate

After determining the stationarity of these series, the study applies Johansen (1988) technique to test for cointegration between agriculture, industry, the service sector, and GDP growth. Cointegration means that a linear combination of two or more time series data can be stationary even if they are not stationary individually (Gujarati 2011). Cointegration occurs when a linear combination of non-stationary variables becomes stationary. However, a linear combination of integrated variables can also become stationary. In this scenario, the variables are considered to be cointegrated. The cointegration technique estimates the number of cointegration vectors by using two tests: maximal Eigen value statistics and trace statistics. The trace statistic assesses the null hypothesis of at most r cointegrating vectors, while the maximal Eigen value test analyzes the null hypothesis of exactly r cointegrating vectors.

4.3. Vector error correction model

When cointegration between series is observed, Vector Error Correction Model (VECM) (Sargan 1964) is used to determine the properties of the cointegrated series. We know that there is a long-term balance between the series when cointegration is observed. We use VECM to establish the short-term characteristics of the cointegrated series.

It is our main undertaking to assess the impact of agriculture on the overall economy. In this context, the model of long-run economic growth and agricultural output is defined as follows:

$GDP_t = \beta_0 + \beta_1 AGRIOUTPUT_t + \beta_2 INDOUTPUT_t + \beta_3 GCF_t + u_t$

Where; β's represents the estimated coefficient, t and u represent the time trend, stochastic error term respectively.
Here,

GDP = Gross Domestic Product Growth,
AGRIOUTPUT = Agricultural value added per worker,
INDOUTPUT = Industrial value added per worker
GCF = Gross capital formation.

Consequently, VECM was applied to explore the short run dynamics to investigate the impact of agricultural output on economic growth. The model to be applied is expressed below:

$\Delta GDP_t = \gamma_0 + \gamma_1 \Delta AGRIOUTPUT_t + \gamma_2 \Delta INDOUTPUT_t + \gamma_3 \Delta GCF_t + \gamma_4 u_{t-1} + \varepsilon_t$

Where; γ's represents the coefficient to be estimated, ε is the white noise error term. u_{t-1} is the lagged of error correction term and γ_4 are the coefficient of error correction which is expected to be negative.
If the ECM (u_{t-1}) coefficient is negative and significant, any short-term deviations between independent and dependent variables lead to a stable, long-term relationship between variables.

4.4. Granger causality test

The general specification of the bivariate (X, Y) sense Granger causation test is:

$Y_t = \alpha_0 + \alpha_1 Y_{t-i} + \ldots\ldots\ldots\ldots + \alpha_i Y_{t-i} + \beta_1 X_{t-i} + \ldots\ldots\ldots \beta_i X_{t-i} + \mu$

$X_t = \alpha_0 + \alpha_1 X_{t-i} + \ldots\ldots\ldots\ldots + \alpha_i X_{t-i} + \beta_1 Y_{t-i} + \ldots\ldots\ldots \beta_i Y_{t-i} + \mu$

The model's subscriptions are time intervals, and the error represents white noise. The overall co-integration movements between X and Y following the unit root process might be seen as pattern in these variables (Granger 1969). The first investigates the null hypothesis that X does not cause Y in the grangers, whereas the second investigates the null hypothesis that Y does not cause X. This research generates two tests. If we do not reject the latter but manage to dismiss it, we might infer that the changes in X are caused by the change in Y. If one of Equations' null assumptions is rejected, unidirectional causation between two variables will emerge. If both null assumptions are rejected, bidirectional causality exists; otherwise, there is no causality when no hypothesis is rejected of equations.

4.5. Data types and data collection methods

The study examines the nexus between agricultural output and economic growth in Bangladesh. Annual time series data on agricultural output, gross capital formation, industrial output, and economic growth proxy by GDP growth over the period from 1991 to 2019 was collected from secondary sources. The data obtained from World Bank-Bangladesh Development Indicators website include agricultural output, gross capital formation, industrial output and GDP growth.

5. Results and Discussion

This section of the study goes into great detail about the data, the relevance of the relationship between the variables, and the conclusion about the hypothesis that the researcher draws from the results. To investigate the connection, we first tested its stationarity using a unit root test, which revealed that it was significant at first order differences, and then we performed a cointegration test, which revealed that the underlying variables had a long run influence. Furthermore, we use VECM to determine the type of effect.

5.1. Test of stationary: unit root test

The study uses Dickey-Fuller GLS and KPSS test statistics to evaluate unit root of the data series. Table 1 shows that there is no unit root for the underlying data of GDP growth. Because the values of DF-GLS and KPSS are too little in relation to the tabular MacKinnon (1996) and Kwiatkowski (1992) value respectively. From the table we can find that the value for MacKinnon is too negative for DF-GLS and value for Kwiatkowski (1992) too less for KPSS estimates, for which -1.953858 and 0.463000 were drafted in MacKinnon and Kwiatkowski-Phillips-Schmidt-Shin, of DF-GLS and KPSS estimates -4.087676 and 0.145998 in the first difference. On the other hand, the level values are insignificant as the values are not negative enough and lesser. The values are measured at 5% level of significance. Therefore, in terms of DF-GLS, the null hypothesis for the unit root has been rejected, meaning the data is stationary in first difference.

In LOGAOUTPUT (agriculture value added per worker), the value of DF-GLS and KPSS test statistics can be shown to be enough negative and too lesser to exceed the formulated value of MacKinnon and Kwiatkowski-Phillips-Schmidt-Shin respectively. The DF-GLS and KPSS test results are -1.975657 and 0.258281 where MacKinnon and Kwiatkowski-Phillips-Schmidt-Shin tabular results are -1.953858 and 0.463000 respectively in first difference. Conversely, you can see the level values are not negative enough and too lesser to be significant. All the estimated values consider the level of significance at 5%, which means that the null hypothesis is rejected in case of DF-GLS alternatively failed to reject by KPSS and the information is stationary in first difference.

GCF (gross capital formation) thus demonstrates, as with previous results, that DF-GLS and KPSS test statistics exceed the tabulated values of MacKinnon and Kwiatkowski-Phillips-Schmidt-Shin. The DF-GLS and KPSS test results at first difference are -4.074283 and 0.195871 where MacKinnon's and Kwiatkowski-Phillips-Schmidt-Shin results are -1.954414 and 0.463000, which reveal GCF is stationary at first difference. The results stimulated in the rejection on the other hand failed to reject of the null hypothesis and stationary data, is also significant at 5 percent in first difference.

Finally, if we scrutiny at the outcomes of INDOUTPUT (industrial output added per worker), it also includes a similar result. When compared to the value formulated by the MacKinnon and Kwiatkowski-Phillips-Schmidt-Shin for INDOUTPUT, the result of the DG-GLS and KPSS test is significantly too negative and less. In first difference the t-statistic of DF-GLS and KPSS have a value of -2.358984 and 0.178071, while those of MacKinnon and Kwiatkowski-Phillips-Schmidt-Shin have a tabular value of -1.953858 and 0.463000. On the contrary, the level values are not significant according to the test specifications. This means the data is stationary at 5% level of significance as the null hypothesis is rejected and vis-à-vis in first difference.

Table 1 shows that for an all-time series, null hypothesis is rejected and vis-à-vis as the unit root values of GF-GLS and KPSS are smaller than critical values in first difference. Therefore, the variables are stationary and integrated in the same order, i.e. I(1) . Briefly, all the variables are stationary and have no unit root in the first difference.

Table 1- (A): DF-GLS

Variables	*Level*		*First difference*	
	t-statistics	*5% critical values*	*t-statistics*	*5% critical values*
GDP Growth	-1.190232	-1.953381	-4.087676*	-1.953858
LOGAOUTPUT	0.117191	-1.953858	-1.975657*	-1.953858
INDOUTPUT	1.996544	-1.953381	-2.358984*	-1.953858
GCF	-0.176767	-1.953858	-4.074283*	-1.954414

*: indicates 5% level of significance

Table 1- (B): Kwiatkowski-Phillips-Schmidt-Shin (KPSS)

Variables	*Level*		*First difference*	
	t-statistics	*5% critical values*	*t-statistics*	*5% critical values*
GDP Growth	0.657029*	0.463000	0.145998	0.463000
LOGAOUTPUT	0.665894*	0.463000	0.258281	0.463000
INDOUTPUT	0.637055*	0.463000	0.178071	0.463000
GCF	0.683958*	0.463000	0.195871	0.463000

*: indicates 5% level of significance

5.2. The Johansen test for cointegration estimate

In order to find a relation scenario for these variables, we use the Johansen cointegration test. The optimal lag length for the VEC mechanism was determined before we took the test. To determine the optimal lag, we took the considerable value of the AIC criterion and found that there were 2 optimal lengths of lag. Therefore, we evaluated Johansen's cointegration and the result is stated below:

Table 2- Unrestricted Cointegration Rank Test (Trace)

Hypothesized No. of CE(s)	***Eigenvalue***	***Trace Statistics***	***Critical Value at 5%***	***Prob.*****
None *	0.759393	67.19754	47.85613	0.0003
At most 1 *	0.610763	30.15824	29.79707	0.0454
At most 2	0.192414	5.625502	15.49471	0.7393
At most 3	0.002656	0.069161	3.841466	0.7925

Trace test indicates 2 cointegrating eqn(s) at the 0.05 level. *: denotes rejection of the hypothesis at the 0.05 level, **: MacKinnon-Haug-Michelis (1999) p-values.

Table 3- Unrestricted Cointegration Rank Test (Maximum Eigenvalue)

Hypothesized No. of CE(s)	***Eigenvalue***	***Max-Eigen Statistic***	***0.05 Critical Value***	***Prob.*****
None *	0.759393	37.03931	27.58434	0.0023
At most 1 *	0.610763	24.53274	21.13162	0.0159
At most 2	0.192414	5.556341	14.26460	0.6706
At most 3	0.002656	0.069161	3.841466	0.7925

Max-eigenvalue test indicates 2 cointegrating eqn(s) at the 0.05 level, *: denotes rejection of the hypothesis at the 0.05 level, **: MacKinnon-Haug-Michelis (1999) p-values

Tables 2 and 3 describe the findings of the Johansen bivariate co-integration tests. The empirical results show that trace test values and max-eigan value tests are statistically significant (P>0.05) and above the critical values for the models underlying the data. In this regard, maximum eigan value and trace statistics reject the null hypothesis of no-co-integration (r = 0). In other words, there is a long run relationship between gross domestic product growth and agricultural output per worker and so on.

5.3. Serial correlation test

A good model can sometimes have the serial correlation problem, which causes the model to dilemma in terms of reliability. In this model, however, the VEC mechanism residual series shows that the model is not auto correlated. Using Breusch-Godfrey Serial Correlation LM Test, where we failed to reject the null hypothesis of no serial correlation at 5% level of significance (see table 8 in appendix).

5.4. Heteroskedasticity tests

The heteroskedasticity test is a method to determine whether or not anything is heteroskedastic. The lack of heteroskedastic is a prerequisite of a stable model in the variable distribution system. The Breusch-Pagan-Godfrey test shows that there is no problem of heteroskedasticity in the residual series because the study has failed to reject the null hypothesis of no heteroskedasticity at 5% significant level, reported in table 9 (appendix).

5.4. CUSUM and CUSUM of squares test

The study uses CUSUM and CUSUM of Squares recursive estimates of residuals to check the stability of the model. We can infer that the model is well stabilized on the basis of the graphic view, as the model's value is all between the red marked lines in figure 3 and 4 (appendix).

5.5. Normality test of residuals

The research also checks the distribution properties of the regression residuals. As the results shows that the Jarque Bera probability value is 80 which indicates the residual series of the estimated model is normally distributed, reported in figure 5 (appendix).

5.6. Vector error correction model (VECM) estimates

Long-term relationship or equilibrium between agricultural output, industrial output, gross capital formation and GDP is established through cointegration analysis. While in the short run, the economy may be in disequilibrium. Sargan (1964) error correction strategy was later incorporated into Engle and Granger and thrives in disequilibrium. The correction term directs the figures (GDP, LOGAGRIOUTPUT, INDOUTPUT and GCF to equalize once again. The error correction term has to be negative and significant. This value of negative error correction term means the speed of restoring the disequilibrium into equilibrium.

Table 4- Vector Error Correction Results

Standard errors in ( ) & t-statistics in [ ]				
Cointegrating Eq:	*CointEq1*			
GDP_GROWTH(-1)	1.000000			
LOGAGRIOUTPUT(-1)	-2.779156			
	(0.48919)			
	[-5.68113]			
INDOUTPUT(-1)	-0.000376			
	(0.00043)			
	[-0.87648]			
GCF(-1)	0.115935			
	(0.09763)			
	[1.18753]			
C	10.36032			
Error Correction:	D (GDP_GROWTH)	D (LOGAGRIOUTPUT)	D (INDOUTPUT)	D (GCF)
CointEq1	-0.663738	0.019801	129.5281	-0.071815
	(0.40704)	(0.00871)	(85.1104)	(0.20808)
	[-1.63066]	[2.27432]	[1.52188]	[-0.34513]
D(GDP_GROWTH(-1))	0.132613	-0.001196	-4.259410	0.238852
	(0.21724)	(0.00465)	(45.4235)	(0.11105)
	[0.61046]	[-0.25735]	[-0.09377]	[2.15080]
D(LOGAGRIOUTPUT(-1))	9.961722	0.323189	-870.7098	-8.095628
	(7.42976)	(0.15892)	(1553.55)	(3.79817)
	[1.34079]	[2.03368]	[-0.56047]	[-2.13146]
D(INDOUTPUT(-1))	-0.000807	-0.000127	0.167684	-0.000611
	(0.00135)	(2.9E-05)	(0.28220)	(0.00069)
	[-0.59798]	[-4.40815]	[0.59420]	[-0.88528]
D(GCF(-1))	0.240625	-0.010321	48.24023	0.250791
	(0.33406)	(0.00715)	(69.8505)	(0.17077)
	[0.72031]	[-1.44440]	[0.69062]	[1.46856]
C	-0.297915	0.041807	93.07227	0.681615
	(0.46190)	(0.00988)	(96.5819)	(0.23613)
	[-0.64498]	[4.23154]	[0.96366]	[2.88665]

The results of VECM demonstrates that the error correction coefficient is negative which is not significant at 5%. However, this implies that the system corrects previous term deviation of disequilibrium at the speed of 66.4% between the variables of GDP Growth, AGRIOUTPUT, INDOUTPUT and GCF.

5.7. Testing the transmission of shocks:

Table 5- Impulse Response Function

Period	*GDP_GROWTH*	*LOGAGRIOUTPUT*	*INDOUTPUT*	*GCF*
1	0.636940	0.000000	0.000000	0.000000
2	0.347145	0.178194	-0.064065	0.047750
3	0.080491	0.205796	-0.163667	-0.026414
4	-0.080598	0.190073	-0.111042	-0.077518
5	-0.087564	0.154221	-0.081318	-0.104570
6	-0.025396	0.137050	-0.055321	-0.100573
7	0.033172	0.138550	-0.058256	-0.087768
8	0.054747	0.149978	-0.069689	-0.078172
9	0.046382	0.160211	-0.081019	-0.076520
10	0.028463	0.164939	-0.085729	-0.079777

Cholesky Ordering: GDP_GROWTH LOGAGRIOUTPUT INDOUTPUT GCF

To investigate the shock transmission of the variables the data of 29 years is converted into a period of ten years. The impulse response function is estimated between the variables to see the response of transmission of shocks. Where it shows that GDP responds positively only to shocks in LOGAGRIOUTPUT but negatively to INDOUTPUT and GCF. We notice from the table that shocks from the agricultural output per worker is higher than the others variables shocks which are negative. This is also shown in the graph below. That means the agricultural output has positive impact and higher influence on GDP growth of Bangladesh. Similarly, Figure 1 depicts that shocks in LOGAGRIOUTPUT positively influences GDP. However, shocks in INDOUTPUT and GCF negatively respond to GDP.

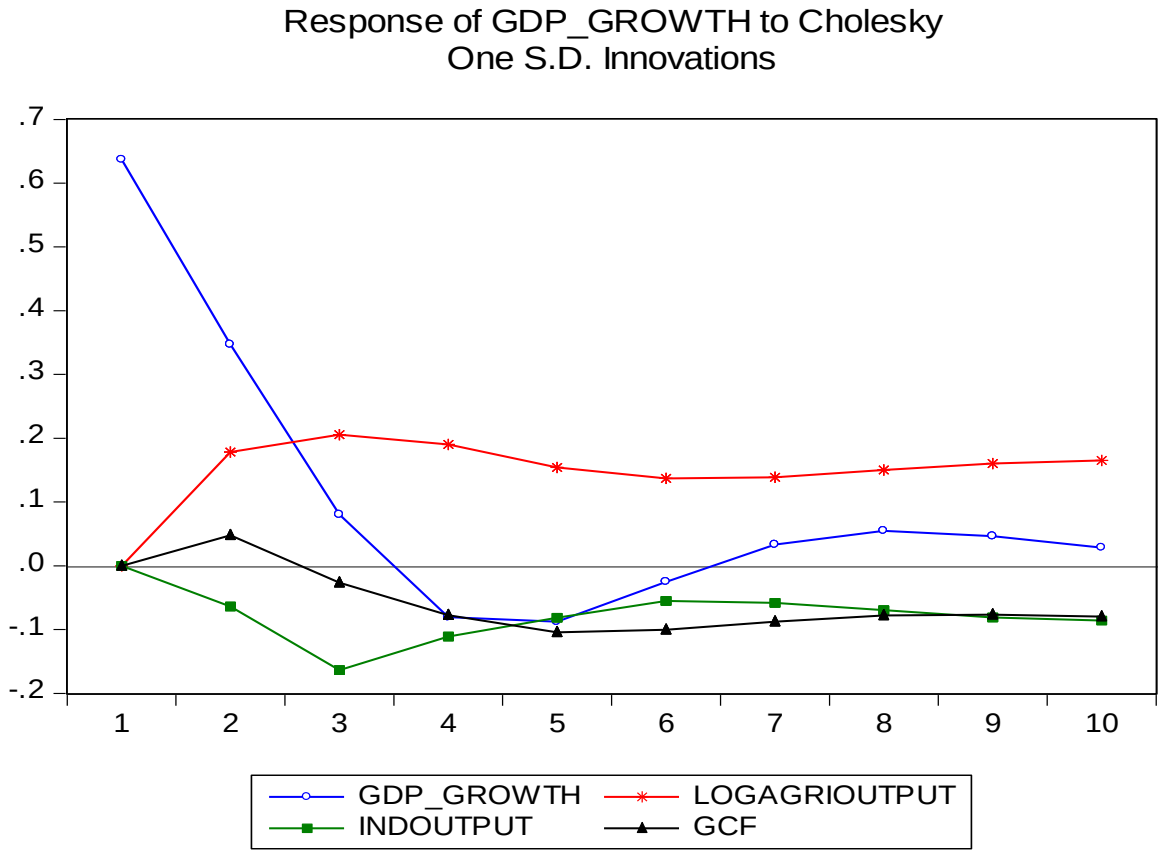

Figure 1- Response of GDP_GROWTH to Cholesky One S.D. Innovations

Table 6- Variance Decomposition

Period	*S.E.*	*GDP_GROWTH*	*LOGAGRIOUTPUT*	*INDOUTPUT*	*GCF*
1	0.636940	100.0000	0.000000	0.000000	0.000000
2	0.751226	93.24211	5.626592	0.727280	0.404014
3	0.800410	83.14631	11.56706	4.821837	0.464793
4	0.837627	76.84763	15.71122	6.160291	1.280861
5	0.866382	72.85264	17.85421	6.639104	2.654042
6	0.884998	69.90235	19.50914	6.753488	3.835022
7	0.902560	67.34355	21.11376	6.909837	4.632855
8	0.922536	64.81088	22.85223	7.184477	5.152416
9	0.944093	62.12635	24.70031	7.596584	5.576749
10	0.965940	59.43467	26.51137	8.044524	6.009441

Cholesky Ordering: GDP_GROWTH LOGAGRIOUTPUT INDOUTPUT GCF

To explore the transmission of shocks received by GDP Growth to its essential sources, we further apply the variance decomposition test. The result is demonstrated through table and graphical view. The major influence to variation in GDP is caused by its feedback to shocks. For the first two years, agricultural output accounts for 2% of GDP, but for the next ten years, it's about 27% of GDP. Though the analysis of impulse response demonstrate that industry output and capital have negative impact on economy, this analysis demonstrates the opposite results. As a whole, industrial output is contributed to shocks in GDP Growth for the first three years is almost 5 percent and remained at 8 percent at the ten years period.

Capital contribution to shocks in GDP is about 1 percent for the first four years and 6 percent for the ten years period. This is also shown in Figure 2. Thus, apart from feedback and industrial output shocks, GDP is most influenced by agricultural output (AGRIOUTPUT).

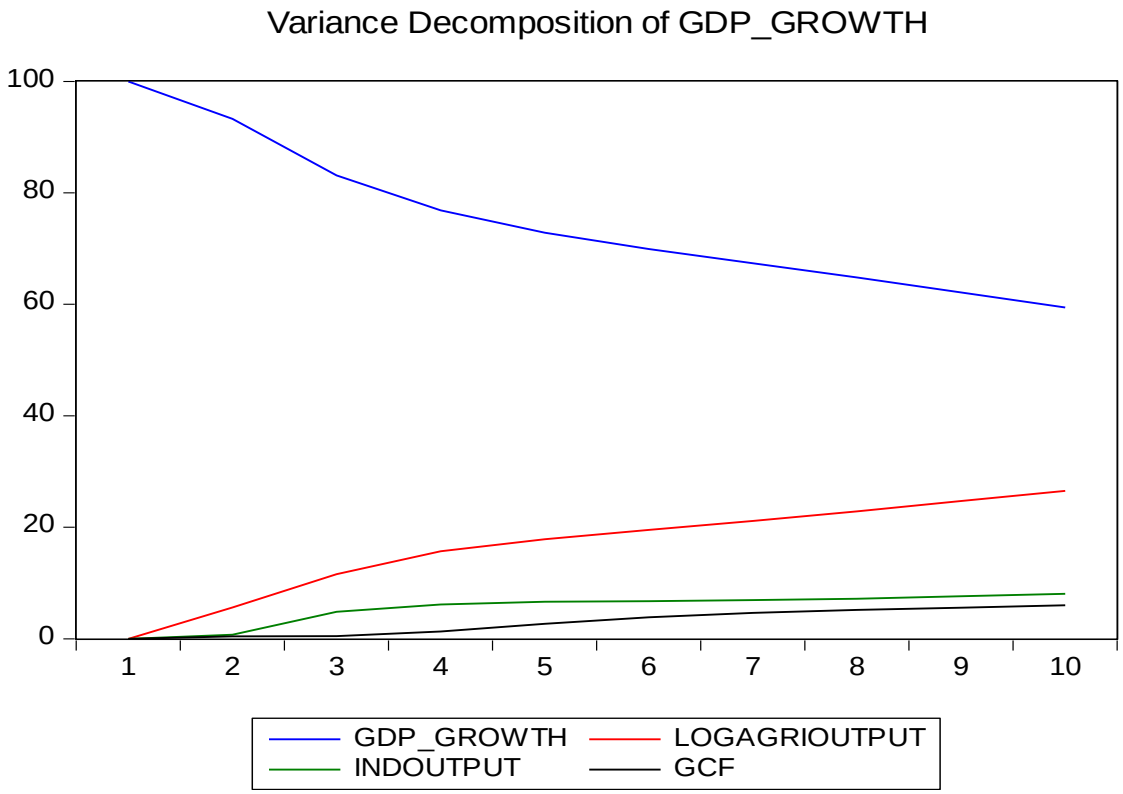

Figure 2- Variance Decomposition of GDP_GROWTH

5.8. Granger causality test

Since we cannot determine the causal direction of the variable through the cointegration test, we use the granger causality mechanism. In this case we use pairwise granger causality test in the model equation to know the causal direction among variables. The causality in pairs shows the variable unidirectional, bidirectional or no directional cause at all.

Table 7 shows the results of estimates of granger causality for the same variables. F-Statistics and the probability of causality between variables were used in this research. Under the non-causality hypothesis, statistics from F-Statistics and probable values determined under the null non-causality hypothesis demonstrate the causal relationship of certain variables. The results of pairwise analysis are shown in Table 7. The null hypothesis is rejected when the probability is less than 5%; otherwise, the null hypothesis is not rejected when the probability value is greater than 5%. The study concludes that the causal relationship between LOGAGRIOUTPUT and GDP Growth is one-way. Where the causality runs from LOGAGRIOUTPUT to GDP Growth. Consequently, the other variables also enclose unidirectional causal relationship except the INDOUTPUT and GDP growth has bidirectional causality but in the case of the INDOUTPUT and GCF there exists no causality. Therefore, we can suppose that the model has a variety of causal relationships, and therefore the causal results are consistent over the long term.

Table 7- Pairwise Granger Causality Test

Null Hypothesis:	*Obs.*	*F-Statistic*	*Prob.*	*Decision*
LOGAGRIOUTPUT does not Granger Cause GDP_GROWTH	27	6.13118	0.0076	Reject
GDP_GROWTH does not Granger Cause LOGAGRIOUTPUT		1.56520	0.2314	Do not Reject
INDOUTPUT does not Granger Cause GDP_GROWTH	27	3.96691	0.0338	Reject
GDP_GROWTH does not Granger Cause INDOUTPUT		3.93326	0.0346	Reject
GCF does not Granger Cause GDP_GROWTH	27	5.07265	0.0154	Reject
GDP_GROWTH does not Granger Cause GCF		1.41384	0.2645	Do not Reject
INDOUTPUT does not Granger Cause LOGAGRIOUTPU	27	7.05561	0.0043	Reject
LOGAGRIOUTPUT does not Granger Cause INDOUTPUT		1.38943	0.2702	Do not Reject
GCF does not Granger Cause LOGAGRIOUTPUT	27	3.49441	0.0481	Reject
LOGAGRIOUTPUT does not Granger Cause GCF		1.91444	0.1712	Do not Reject
GCF does not Granger Cause INDOUTPUT	27	2.63447	0.0943	Do not Reject
INDOUTPUT does not Granger Cause GCF		1.66185	0.2127	Do not Reject

6. Discussion

The utilization of VECM in this study offers a sophisticated analytical lens for understanding the dynamic interaction between agricultural output and economic growth over the long and short term. This approach is particularly relevant given the complexities inherent in Bangladesh's economy, which is characterized by a transitioning agrarian base towards more industrial and service-oriented sectors. Previous studies such as Siddique and Selvanathan (2012) and Nath and Mamun (2005), while insightful, primarily focused on specific economic factors like remittances and exports using simpler econometric models. This study's comprehensive methodological framework allows for a more detailed examination of the multifaceted relationship between agriculture and economic growth, considering both immediate and gradual effects.

The findings reveal a significant long-run relationship between agricultural output and economic growth, with agriculture exerting a more pronounced influence on economic prosperity than industrial output. This underscores the pivotal role of agriculture in sustaining economic development, a theme that resonates with the theory of "agricultural demand-led" industrialization posited by Adelman (1984). In contrast, earlier research such as that by Hossain et al. (2018) and Hossain & Wadood (2020) primarily highlighted the contributions of sectors like finance and tourism to economic growth, with less emphasis on agriculture. This study thus reinstates the agricultural sector's foundational significance in Bangladesh's economic prosperity, advocating for policies that synergize agricultural productivity with overall economic development strategies.

The emphasis on agriculture's primordial role in economic prosperity derived from this study suggests a strategic pivot towards agricultural investment and modernization, aligning with insights from Rahman and Salim (2013) and Ghimire et al. (2021), who also underscored agriculture's critical contribution to GDP and employment. However, the specific recommendation for a balanced funding approach towards both agriculture and industry presents a nuanced policy perspective not extensively covered in earlier works. This suggests an integrated development model where agriculture remains a central focus, even as industrial and service sectors are nurtured for a holistic economic advancement.

This study contributes uniquely to the literature by:

a) Employing a VECM Approach: Offering a refined understanding of the temporal dynamics between agricultural output and economic growth.
b) Emphasizing Agriculture's Central Role: Reinforcing the importance of agriculture for sustainable economic development in the context of Bangladesh's transitioning economy.
c) Advocating Balanced Development Strategies: Proposing nuanced policy recommendations that advocate for simultaneous investments in agriculture and industry to foster sustainable development,

7. Conclusions

The study contributes to find a long-run link between agricultural production, capital, industrial output, and GDP. At a speed of 66.4 percent, the short run disequilibrium will be reached at a settled point. Aside from feedback almost equal industrial output and capital shocks, agriculture sector shocks have a noticeable impact on economic growth. This implies that the agriculture sector is primordial to economic prosper of Bangladesh. Notably, through industrial output has moderate impact on economic growth, the agricultural output has much more robust influence on economic development. The findings give insights to policy guidelines. Economically, as the agriculture in Bangladesh has a significant role in the economy, it requires to do enough investment from private and public sector to boost agriculture. And the government should bring new technologies to make agriculture more efficient and productive, which will ensure food security for all. In addition, policymakers take a balanced approach to flow funds for both agriculture and industrial sectors. This balanced strategy will pave the way for achieving sustainable development, maintaining food security by minimizing inflationary pressure, which will bring social stability. It is also recommended that the government and other pertinent authorities take a more active role in bringing the agricultural sector to the forefront of planning related to economic policy, acknowledging its vital role in driving economic growth and serving as a pillar of sustainable development in Bangladesh. On the other hand, the study has some limitations, despite doing extensive research on this field. The conclusion is drawn only using a certain period's data. Secondly, the study only focuses on Bangladesh economy, but the panel data could provide better result and understanding in the context. Thirdly, the study did not consider the ecological and environmental issues. Future studies can consider all issues to overcome the shortcomings, including the ecological footprint.

References

Adelman I (1984). Beyond export-led growth. World development 12(9): 937-949

Adhikary B K (2010). FDI, Trade Openness, Capital Formation, and Economic Growth in Bangladesh: A Linkage Analysis. *International Journal of Business and Management*. https://doi.org/10.5539/ijbm.v6n1p16

Alam, G. (2008). The role of technical and vocational education in the national development of Bangladesh. *International Journal of Work-Integrated Learning* 9(1): 25

Asaduzzaman. (2019). FDI as an Opportunity for Economic Growth of Bangladesh: A VECM Analysis. *SSRN Electronic Journa*l. https://doi.org/10.2139/ssrn.3498742

Bishwajit G, Barmon R & Ghosh S (2014). Reviewing the Status of Agricultural Production in Bangladesh From a Food Security Perspective. *Russian Journal of Agricultural and Socio-Economic Sciences*. https://doi.org/10.18551/rjoas.2014-01.04

Das M R & Hossain M A (2020). Impact of Agricultural Loan Disbursement and Chemical Fertilizer Use on the Rice Production in Bangladesh. *Bangladesh Journal of Public Administration*. https://doi.org/10.36609/bjpa.v27i2.69

Dey S (2022). Impacts of Major Crop Production on the Agricultural Sector in Bangladesh: A Time Series Analysis. *International Journal of Sustainable Agricultural Research*. https://doi.org/10.18488/ijsar.v9i1.2937

Elliott G, Rothenberg T J & Stock J H (1992). Efficient tests for an autoregressive unit root. In: National Bureau of Economic Research Cambridge, Mass., USA.

Ghimire A, Lin F & Zhuang P (2021). The Impacts of Agricultural Trade on Economic Growth and Environmental Pollution: Evidence From Bangladesh Using ARDL in the Presence of Structural Breaks. Sustainability. https://doi.org/10.3390/su13158336

Granger C W (1969). Investigating causal relations by econometric models and cross-spectral methods. *Econometrica: journal of the Econometric Society* pp. 424-438

Gujarati D (2011). Basic Econometrics, Eighth reprint. In: McGraw-Hill Publications, New York.

Hasan S S, Turin M Z, Ghosh M K & Khalil M (2017). Assessing Agricultural Extension Professionals Opinion Towards Sustainable Agriculture in Bangladesh. *Asian Journal of Agricultural Extension Economics & Sociology*. https://doi.org/10.9734/ajaees/2017/33338

Hasanov F, Suleymanov E, Aliyeva H, Eynalov H & Shannak S d (2022). What Drives the Agricultural Growth in Azerbaijan? Insights From Autometrics With Super Saturation. Acta Universitatis Agriculturae Et Silviculturae Mendelianae Brunensis. https://doi.org/10.11118/actaun.2022.012

Hossain B & Wadood S N (2020). Potential Unexplored? Tourism and Economic Growth of Bangladesh. JoT. https://doi.org/10.26650/jot.2020.6.1.0031

Hossain M I, Begum M E A, Papadopoulou E & Semos A (2012). Sectoral Co-Integration and the Role of Agriculture in Bangladesh. *Journal of International Logistics and Trade.* https://doi.org/10.24006/jilt.2012.10.3.105

Hossain M S, Kibria M G & Islam M S (2018). Does Globalization Affect the Economic Growth of Bangladesh? - An Econometric Analysis. Asian Economic and Financial Review. https://doi.org/10.18488/journal.aefr.2018.812.1384.1393

Islam N, Afrin S, Tasnim T, Biswas M P & Shahriar T (2018). Application of Labor Laws and Other Compliances in Readymade Garment Industry of Bangladesh. *Universal Journal of Management*. https://doi.org/10.13189/ujm.2018.060301

Johansen S (1988). Statistical analysis of cointegration vectors. *Journal of economic dynamics and control* 12(2-3): 231-254

Johnston B F & Mellor J W (1961). The role of agriculture in economic development. The American Economic Review 51(4): 566-593

Kelikume I & Nwani S E (2020). Empirical Analysis of Causal Linkage Between Agricultural Output and Real GDP: Evidence From Nigeria. *Asian Journal of Agricultural Extension Economics & Sociology*. https://doi.org/10.9734/ajaees/2020/v38i630363
Kwiatkowski D, Phillips P C, Schmidt P & Shin Y (1992). Testing the null hypothesis of stationarity against the alternative of a unit root: How sure are we that economic time series have a unit root? *Journal of econometrics* 54(1-3): 159-178
Lewis W A (1954). Economic development with unlimited supplies of labour.
Mellor J W (1976). The new economics of growth: a strategy for India and the developing world.
Nath H K & Mamun K A (2005). Export-Led Growth in Bangladesh: A Time Series Analysis. Applied Economics Letters. https://doi.org/10.1080/13504850500068194
Nurkse R (1953). Notas sobre o Trabalho do Sr. Furtado Relativo a" Formação de Capitais e Desenvolvimento Econômico". Revista brasileira de economia 7(1): 67-87
Rahman A, Zhu N, Islam M D I, Anny S A, Afroj M, Sarker N I & Islam M W (2022). Factors Influencing Farmers' Awareness and Risk Perception of Environmental Degradation In Bangladesh. *Polish Journal of Environmental Studies*. https://doi.org/10.15244/pjoes/141344
Rahman S & Salim R (2013). Six Decades of Total Factor Productivity Change and Sources of Growth in Bangladesh Agriculture (1948–2008). *Journal of Agricultural Economics*. https://doi.org/10.1111/1477-9552.12009
Rajib M I & Rahman R (2020). Foreign Direct Investment and Economic Growth: Evidence From Bangladesh Economy. *European Scientific Journal Es*j. https://doi.org/10.19044/esj.2020.v16n10p38
Rezvi M R (2018). The Factors of Declining Agricultural Growth in Bangladesh and Its Impact on Food Security. *South Asian Journal of Social Studies and Economics.* https://doi.org/10.9734/sajsse/2018/v1i425810
Rostow W W (1990). The stages of economic growth: A non-communist manifesto. Cambridge university press.
Salim R, Hassan K & Rahman S (2019). Impact of R&D Expenditures, Rainfall and Temperature Variations in Agricultural Productivity: Empirical Evidence From Bangladesh. Applied Economics. https://doi.org/10.1080/00036846.2019.1697422
Sargan J D (1964). Three-stage least-squares and full maximum likelihood estimates. Econometrica: journal of the Econometric Society pp. 77-81
Shahbaz M, Rehman I U & Muzaffar A T (2014). Re-Visiting Financial Development and Economic Growth Nexus: The Role of Capitalization in Bangladesh. South African Journal of Economics. https://doi.org/10.1111/saje.12063
Siddique A & Selvanathan S (2012). Remittances and Economic Growth: Empirical Evidence From Bangladesh, India and Sri Lanka. The Journal of Development Studies. https://doi.org/10.1080/00220388.2012.663904
Wang X, Shilei W & Gao F (2010). The Relationship Between Economic Growth and Agricultural Growth: The Case of China. https://doi.org/10.1109/icee.2010.1330
Yusuf S A (2014). Role of agriculture in economic growth & development: Nigeria perspective.

APPENDIX

Table 1- Serial correlation test, H_0*: No serial correlation,* H_1*: Serial correlation*

Breusch-Godfrey Serial Correlation LM Test:

F-statistic	0.109455	Prob. F(2,19)	0.8969
Obs*R-squared	0.307540	Prob. Chi-Square	0.8575

Table 2- Heteroskedasticity test, H_0: No heteroscedasticity, H_1: Heteroskedastic

Heteroskedasticity Test: Breusch-Pagan-Godfrey

F-statistic	1.326100	Prob. F(8,18)	0.2926
Obs*R-squared	10.01222	Prob. Chi-Square(8)	0.2642
Scaled explained SS	5.079983	Prob. Chi-Square(8)	0.7490

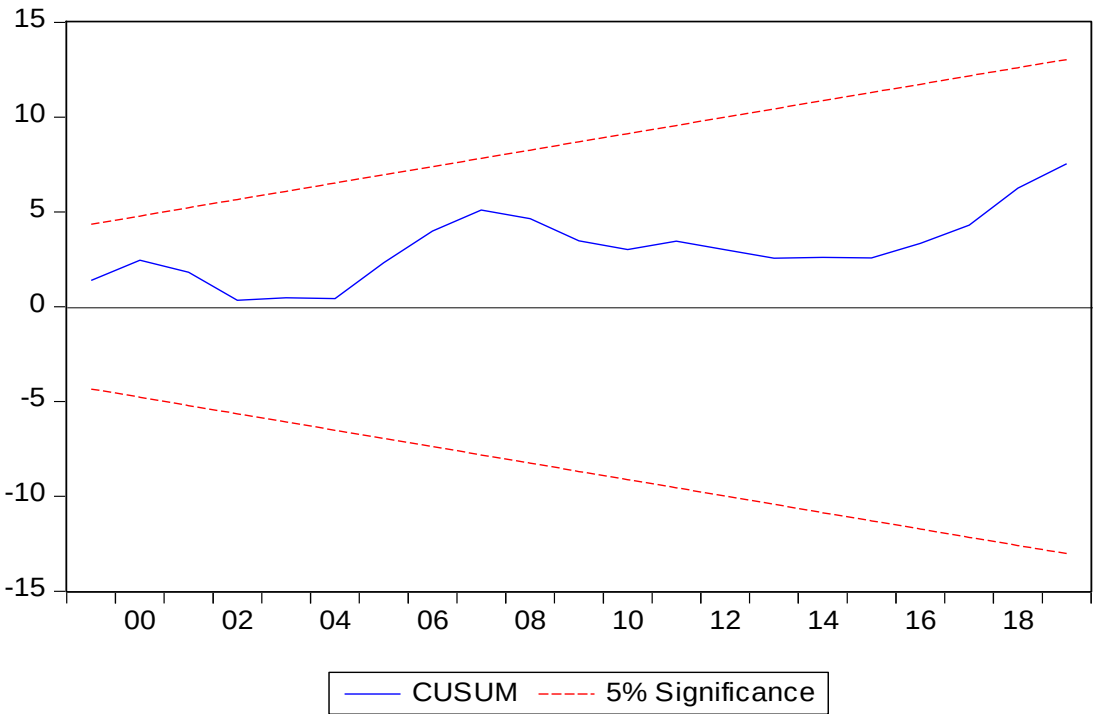

Figure 3 - CUSUM test

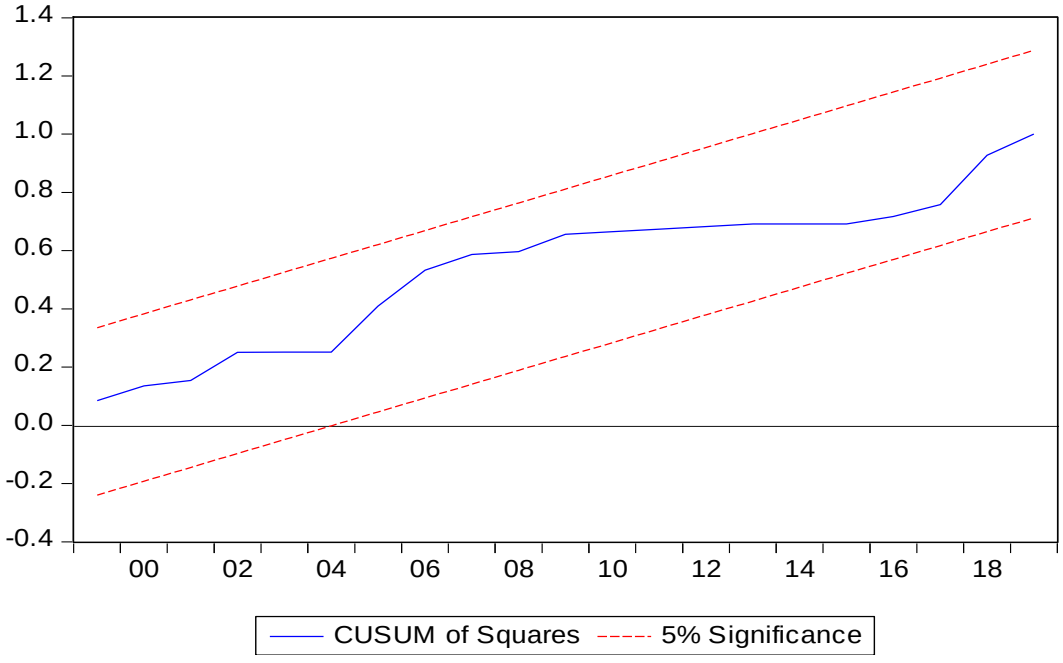

Figure 4- CUSUM of Squares test

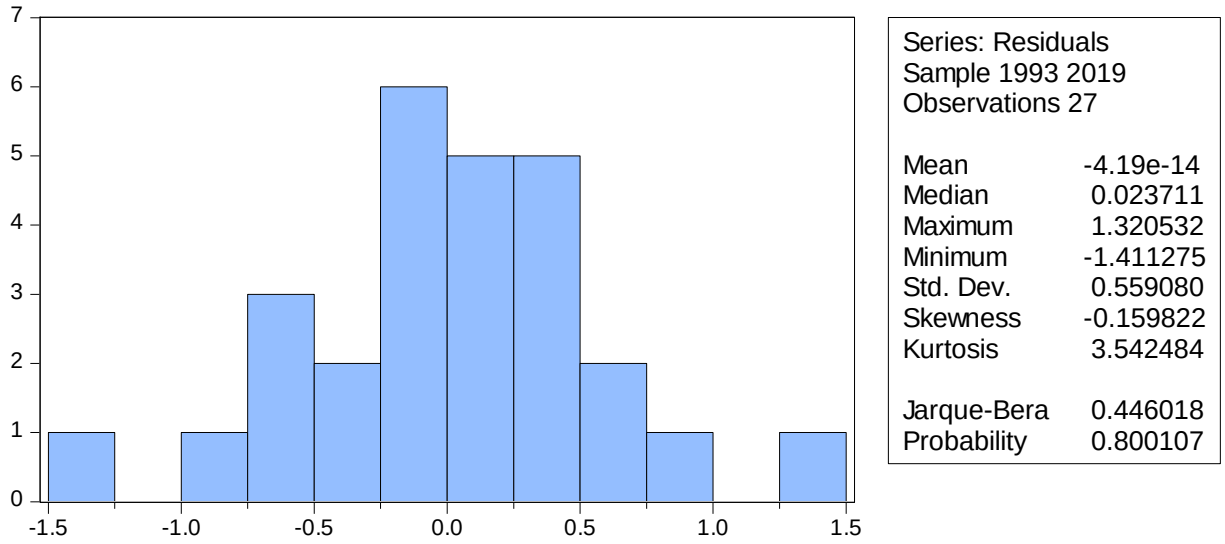

Figure 5- Normality test of residuals

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Impact of Acadian Marine Plant Extract Powder (AMPEP) concentration in nutrient medium on the growth and lipid accumulation of *Chlorella* sp. Culture

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ABSTRACT
Microalga of the genus *Chlorella* has developed a stable industry as dietary supplements for humans and animals based on their scientific and commercial interests. The growth of *Chlorella* sp. cultures has been enhanced by using a variety of nutrients to improve pigmentation, lipid content, and growth. Acadian Marine Plant Extract Powder (AMPEP) improves crops and macroalgae production, such as seaweeds. However, AMPEP has not yet been studied as a means of producing microalgae. Therefore, this study investigates microalgae production in a nutrient medium containing AMPEP. Three concentrations of AMPEP were prepared: group A (125 mg L^{-1} AMPEP), group B (625 mg L^{-1} AMPEP), and group C (0 mg L^{-1} AMPEP) as control. Experiments were conducted for each group for 21 days in triplicate. Results revealed that lower AMPEP (125 mg L^{-1}) concentration added to the nutrient medium provides higher cell densities in *Chlorella* sp. culture. 125 mg L^{-1} AMPEP in a nutrient medium reached the highest cell density of 1.28 fold cell mL^{-1} than the control group. Additionally, the dry weight of groups A, B, and C were calculated as 2.57 ± 0.12 g L^{-1}, 1.37 ± 0.06 g L^{-1}, and 1.58 ± 0.16 g L^{-1}, respectively. The cell sizes of groups A, B, and C were 4.80 ± 1.32 µm, 5.20 ± 1.87 µm, and 3.80 ± 0.79 µm, respectively. Moreover, the highest level of lipid accumulation of *Chlorella* sp. culture was achieved by group B with a lipid content of 10.44 ± 1.28 %, followed by group A with a lipid content of 8.55 ± 0.80 %, which was higher than the control group (group C) with a lipid content of 7.04 ± 0.93 %. Hence, the present study shows that AMPEP used in microalgae production may improve growth and lipid accumulation.

Keywords: AMPEP, *Chlorella* sp., Growth, Pigments, Lipids

1. Introduction

Microalgae are nutrient-rich organisms because of their biochemical composition, particularly their lipid and fatty acid composition (Niccolai et al. 2019). The changes in culture conditions, including medium type, temperature, and light, can significantly affect biochemical composition (Durmaz et al. 2008; George et al. 2014). Microalgae as direct feed in larval tanks is essential in aquaculture for bivalves at all growth stages and for some crustacean and fish species larvae (Kaparapu 2018). In aquaculture, zooplankton transports nutrients from microalgae to larger culture aquatic organisms (Vismara et al. 2003; Montemezzani et al. 2015). In addition, the microalgae industry produces various biotechnological products, such as feed, natural colorants, health foods, bioenergy, and pharmaceuticals (Rizwan et al. 2018; Rahman 2020).

Chlorella sp. is one of the most widely produced microalgae due to its high productivity, cellular composition, and ability to grow photoautotrophically, heterotrophically, and mixotrophically (Caporgno et al. 2019; Erbil & Durmaz 2020). Researchers stated that *Chlorella* sp. contains high levels of pigments, fatty acids, lipids, protein, minerals, and vitamins (Silva et al. 2020; Tayemeh et al. 2020). Microalgae from the genus *Chlorella* are distinguished by the two main types of chlorophylls (*a* and *b*), which are their most abundant pigments, as well as other pigments such as astaxanthin, c-astaxanthin, beta-carotene, and lutein that contribute to their pigment composition (Christaki et al. 2015; Khanra et al. 2018; Silva et al. 2020). The amount of pigments involved in light harvesting depends on the growth conditions, especially the light intensity, the salinity, and the nutrients available (Juneja et al. 2013). Additionally, it has been found that microalgae, mainly green algae, have high levels of lipids, although their productivity varies considerably depending on the species of algae (Griffiths et al. 2012; Wahidin et al. 2013; Khan et al. 2018). It has been found that *Dunaliella*, *Scenedesmus*, and *Chlorella* species have the highest levels of lipids in their cells, ranging from a lipid content of 10 to 67% (Islam et al. 2013; Nascimento et al. 2013; Udayan et al. 2023). It is well

documented that nutrient limitation creates stress conditions in cells, which in turn enhances lipid accumulation in microalgae (Sulochana & Arumugam 2020).

Ascophyllum nodosum is a brown seaweed containing bioactive substances that may influence the molecular, biochemical, and physiological function of crop plants (Di Stasio et al. 2018; Shukla et al. 2019). Several temperate regions worldwide, such as the United Kingdom, Iceland, Ireland, Norway, France, and Canada, where *Ascophyllum nodosum* seaweed thrives abundantly (Hurtado et al. 2009). Additionally, an extract from the brown macroalga *A. nodosum* known as *Ascophyllum* (Acadian) Marine Plant Extract Powder (AMPEP) has been studied for micropropagation and field cultivation of seaweeds, particularly *Kapphycus* species (Hurtado & Critchley 2018; Silva et al. 2019). This extract is widely applied to increase the performance of land crops and has been reported to enhance the growth of some seaweed crops (Umanzor et al. 2019). The use of AMPEP has improved macroalgae growth, decreased diseases, and increased carrageenan quality (Loureiro et al. 2017; Tahiluddin et al. 2022). However, no studies have been conducted on using AMPEP to produce microalgae. Thus, this study aims to investigate the effect of the AMPEP concentration in nutrient medium on microalgae production.

2. Material and Methods

2.1. Microalgae

Freshwater microalga *Chlorella* sp. was used in this study and obtained from the Aquaculture Department, Faculty of Fisheries, Kastamonu University, Türkiye.

2.2. Culture condition

500 mL flat-bottom flasks were used in *Chlorella* sp. culture. BG-11 medium was used as a nutrient medium (Tables 1 and 2). Afterward, AMPEP was added to the flask at different concentrations. The composition of AMPEP is shown in Table 3. Each solution was autoclaved for 20 minutes at 121°C. After autoclaving, experimental groups were inoculated at an initial density of 1.0 x 10^6 cells mL^{-1}. Cultures were made with artificial lighting in the laboratory environment. Fluorescent lamps (MASTER TL-D Super 80 36W/865 1SL/25) were used for lighting. The ventilation of the cultures was carried out with an air motor, and syringe filters with an opening of 0.2 µ were used to prevent contamination. The air conditioner maintained a temperature of 20±1 °C.

Table 1- BG-11 nutrient medium (Erbil et al. 2021)

Solution A	***For 500 mL***
$NaNO_3$	*75.0 g*
Solution B	***For 500 mL***
K_2HPO_4	2.0 g
$MgSO_4.7H_2O$	3.75 g
$CaCl_2.2H_2O$	1.80 g
Citric acid	0.30 g
Ammonium ferric citrate green	0.30 g
$EDTANa_2$	0.05 g
Na_2CO3	1.00 g

Table 2- Trace element composition

Trace element solution	***For 1 000 mL***
H_3BO_3	2.86 g
$MnCl_2.4H_2O$	1.81 g
$ZnSO_4.7H_2O$	0.22 g
$Na_2MoO_4.2H_2O$	0.39 g
$CuSO_4.5H_2O$	0.08 g
$Co(NO_3)_2.6H_2O$	0.05 g

Table 3- Composition of Acadian marine plant extract powder (AMPEP) 0.7 – 0.09 – 14.1 from *Ascophyllum nodosum* (The composition was obtained from the Acadian Seaplants, Product of Canada)

Physical analysis	
Appearance	Brownish-black crystals
Odor	Marine odor
Solubility in water	100%
Typical analysis	
Minerals (Ash)	45-50%
Maximum moisture	6.5%
Minimum alginic acid	10%
Minimum Mannitol	4%
Minimum Amino acids	4%
Nitrogen (N) as organic	0.7%
Phosphorus (P) as water-soluble	0.09%
Total potassium (K)	14.1%

2.3. Experimental design

AMPEP was obtained from the Mindanao State University-Tawi-Tawi College of Technology and Oceanography (MSU-TCTO) Sanga-Sanga, Bongao, Taw-Tawi Philippines. The AMPEP was added to the flask with a nutrient medium, as given in Table 4. The control group does not contain any AMPEP source. The experiment was done in triplicates.

Table 4- Experimental group and AMPEP concentration

Experiment	***Unit***	***AMPEP Concentration***
Group A	mg L^{-1}	125
Group B	mg L^{-1}	625
Group C (Control)	mg L^{-1}	0

2.4. Growth analysis

Every three days, samples of microalgae were collected for cell counting and analysis. A Neubauer hemocytometer was used to count cells daily under the light microscope, and contamination was checked on a regular basis visually. An analysis of the biomass of microalgae was conducted on a dry-weight basis. The dried weight of microalgae was determined by drying 5 mL of each experimental group in an oven at 105 °C for 2 hours (Erbil et al. 2021). The specific growth rate (μ) was calculated by the following below.

$$\mu = \frac{\ln(N_2) - \ln(N_1)}{t_2 - t_1}$$

Where: N_2 is the biomass cell number at the time (t_2). N_1 is the beginning biomass cell number at a time (t_1).

2.5. Cell sizes measurement

Photographs of cells were taken and then transferred to ImageJ Software (National Institutes of Health, USA), where measurements were conducted for each group of cells.

Lipid Analysis

A spectrophotometric method was followed by Mishra et al. (2014) to determine the total amount of lipids. A phospho-vanillin and sulfuric acid solution were used as a reagent in determining the lipid amount of microalgae.

Statistical Analysis

IBM SPSS software version 20 was used to analyze the collected data of growth and lipid accumulation of *Chlorella* sp. culture at $P<0.05$ significance level. Data were presented as mean ± standard error of the mean (SEM). Determination of significant differences was computed through the One-way Analysis of Variance (ANOVA). Levene's Test was used to test for homogeneity of variance, and Duncan's Post-Hoc Test was used to rank the mean (Hairol et al. 2022; Sanuddin et al. 2023).

3. Results

3.1. Growth

The experiment was started at an initial density of 1.0 x 10^6 cell mL^{-1} and was continued for 21 days of culture. 125 mg L^{-1} (group A) and 625 mg L^{-1} (group B) concentrations of AMPEP were used in the medium, and no AMPEP concentration was referred to as control (group C). Figure 1 shows the cell number of *Chlorella* sp. culture at different concentrations of AMPEP in a nutrient medium. Results revealed that the maximum cell number of groups A and B reached 146.00 ± 20.51 x 10^6 cell mL^{-1} and 73.42 ± 9.39 x 10^6 cell mL^{-1}, respectively, after 21 days of culture. The maximum cell number of the control group (group C) reached 113.79 ± 9.41 x 10^6 cell mL^{-1} at 21 days of culture. Group A (125 mg L^{-1}) cell growth was statistically higher ($P<0.05$) from group B (625 mg L^{-1}) and control group (group C). The maximum specific growth rates (SGR) were obtained at six days of culture for all experimental groups. SGR of groups A, B, and C were 0.60 ± 0.06 day^{-1}, 0.29 ± 0.12 day^{-1}, and 0.61 ± 0.08 day^{-1}, respectively, of which 125 mg L^{-1} concentration of AMPEP in a nutrient medium and control group were significantly higher than 625 mg L^{-1} concentration of AMPEP (Figure 2). Moreover, it was observed that the cell sizes of groups A, B, and C were 4.80 ± 1.32 µm, 5.20 ± 1.87 µm, and 3.80 ± 0.79 µm, respectively, of which no significant differences ($P<0.05$) were observed among experimental groups (Figure 3). The maximum dry weight of groups A, B, and C were calculated as 2.57 ± 0.12 g L^{-1}, 1.37 ± 0.06 g L^{-1}, and 1.58 ± 0.16 g L^{-1}, respectively. There was a significant difference ($p>0.05$) observed among the experimental group, of which a lower concentration of AMPEM (125 mg L^{-1}) produced higher dry weight than the higher concentration of AMPEP (125 mg L^{-1}) and the control group (Figure 4). In terms of cellular dry weight, groups A, B, and C achieved 20.04 ± 4.27 pg. $cell^{-1}$, 18.86 ± 2.36 pg. $cell^{-1}$, and 14.06 ± 1.03 pg. $cell^{-1}$, respectively, of the cellular dry weight of *Chlorella* sp. culture (Figure 5).

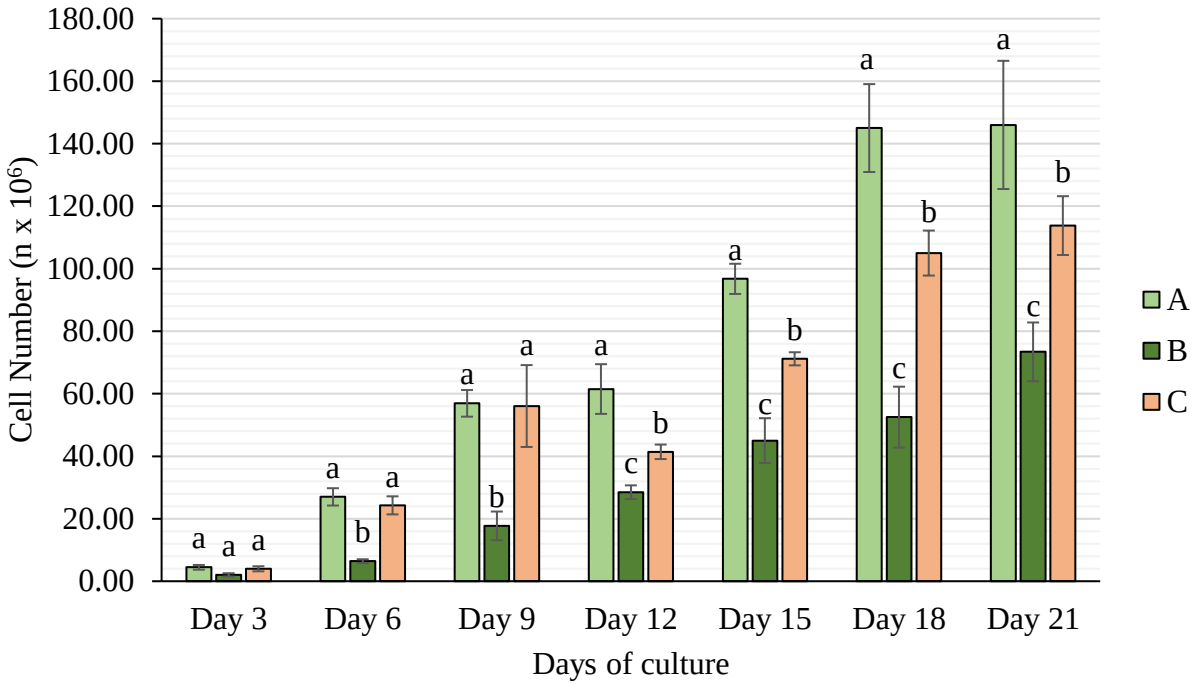

Figure 1- Cell number (n x 10^6) of *Chlorella* sp. culture at different concentrations of AMPEP. Group A (125 mg L^{-1}), group B (625 mg L^{-1}), and group C (Control). Differences in the letters are significantly different ($P<0.05$). Mean error bars are in STD (standard deviation).

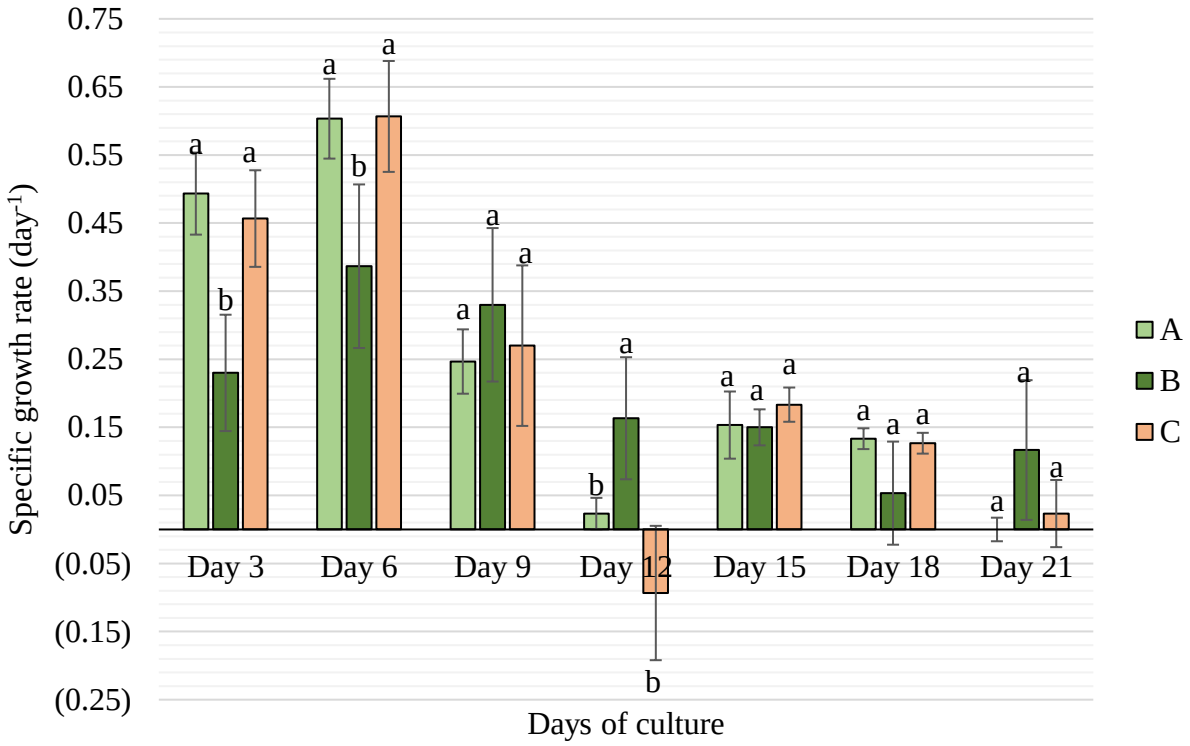

Figure 2-The specific growth rate of *Chlorella* sp. culture at different concentrations of AMPEP. Group A (125 mg L^{-1}), group B (625 mg L^{-1}), and group C (Control). Differences in the letters are significantly different (P<0.05). Mean error bars are in STD (standard deviation).

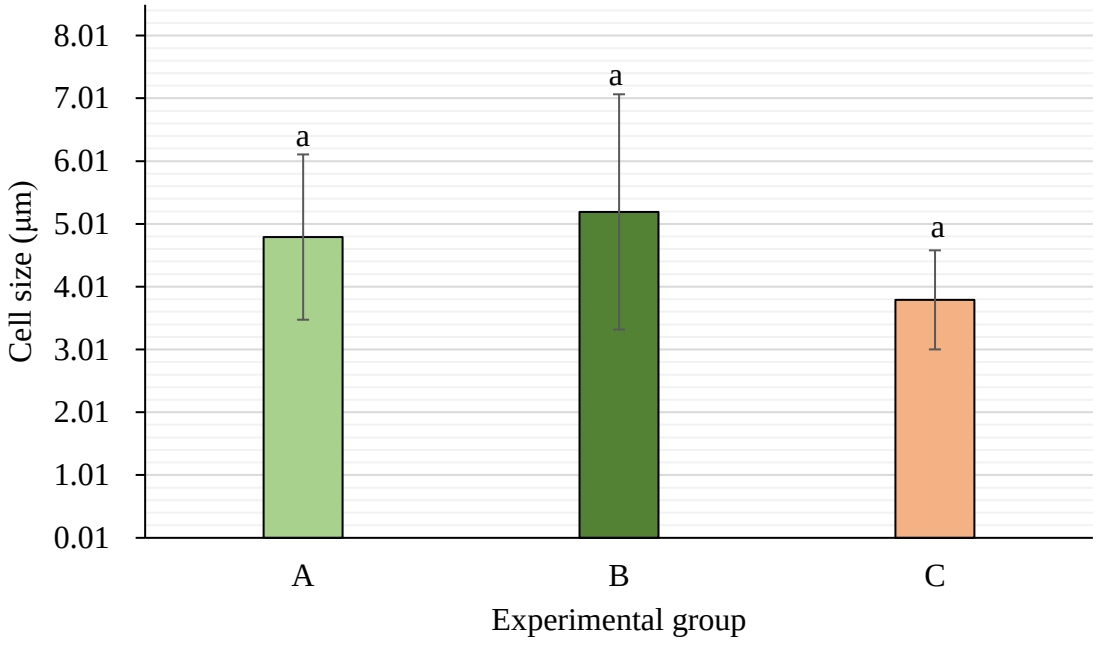

Figure 3- Cell size (µm) of *Chlorella* sp. culture at different concentrations of AMPEP. Group A (125 mg L^{-1}), group B (625 mg L^{-1}), and group C (Control). Differences in the letters are significantly different (P<0.05). Mean error bars are in STD (standard deviation), n=30.

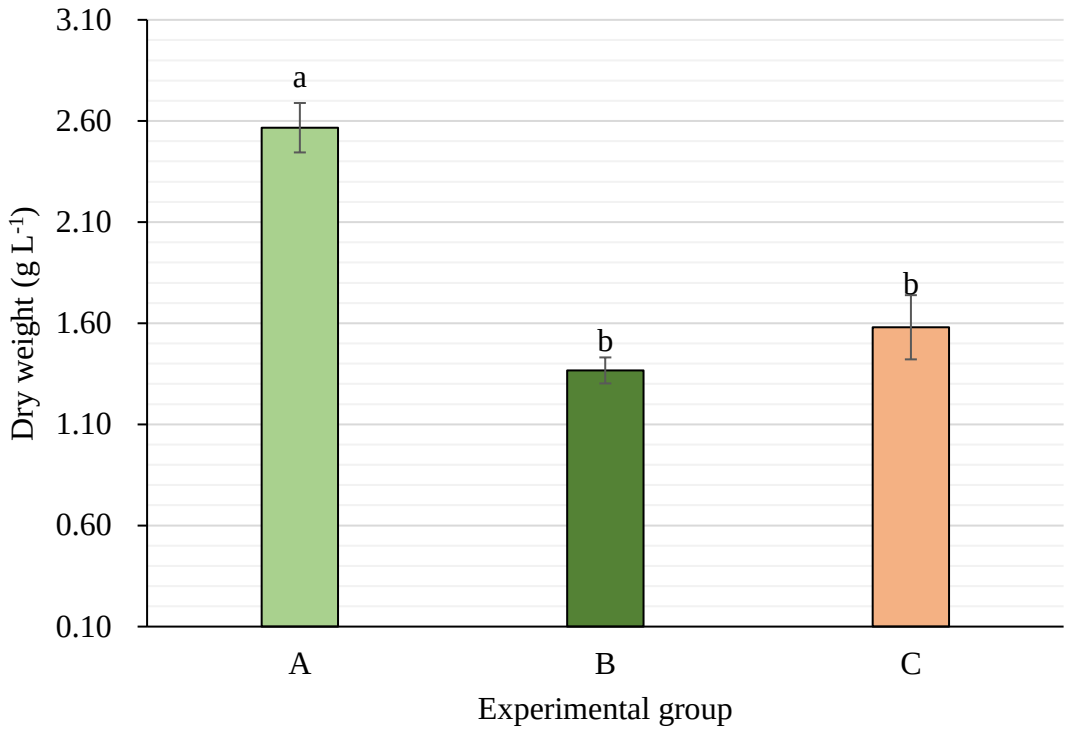

Figure 4- Dry weight (g L^{-1}) of *Chlorella* sp. culture at different concentrations of AMPEP. Group A (125 mg L^{-1}), group B (625 mg L^{-1}), and group C (Control). Differences in the letters are significantly different (P<0.05). Mean error bars are in STD (standard deviation).

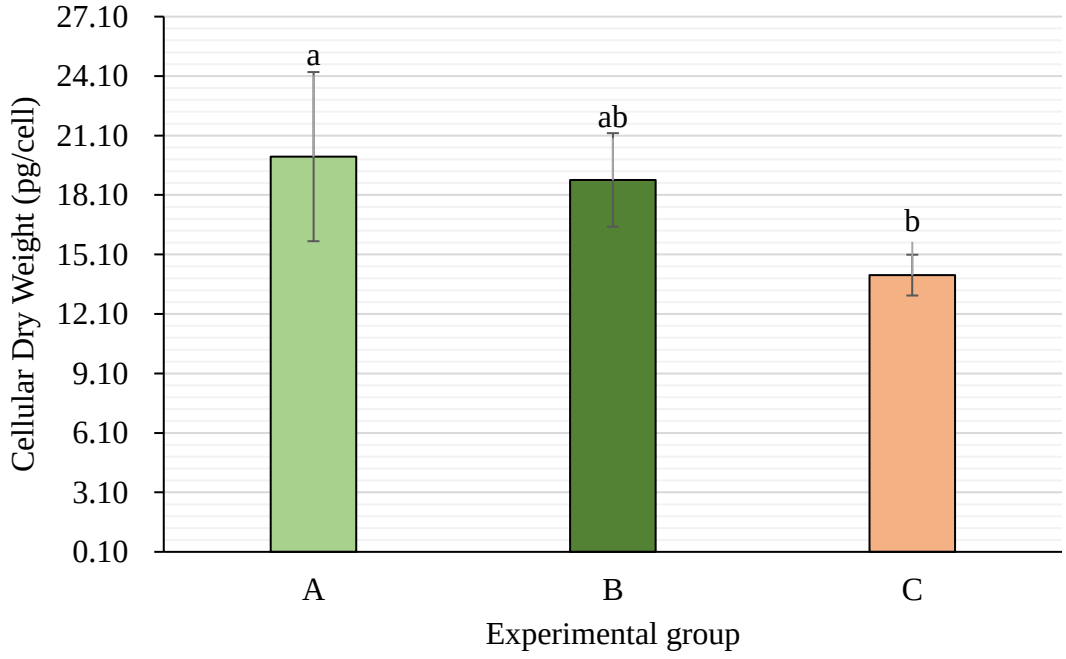

Figure 5- Cellular dry weight (pg. $cell^{-1}$) of *Chlorella* sp. culture at different concentrations of AMPEP. Group A (125 mg L^{-1}), group B (625 mg L^{-1}), and group C (Control). Differences in the letters are significantly different (P<0.05). Mean error bars are in STD (standard deviation).

3.2. Lipid

Figure 4 shows lipid accumulation of *Chlorella* sp. culture at different concentrations of AMPEP in a nutrient medium. The measurement of lipid accumulation was done in triplicates. The maximum lipid content of 625 mg L^{-1} (group B) concentration of AMPEP in the nutrient medium was 10.44 ± 1.28%, while the maximum lipid content of 125 mg L^{-1} (group B) concentration of AMPEP (group A) was 8.56 ± 0.80%. The maximum lipid content in the control group (group C) reached 7.04 ± 0.93%. The lipid content showed no significant difference ($P>0.05$) observed between 125 mg L^{-1} (group A) and 625 mg L^{-1} (group B) of AMPEP added to *Chlorella* sp. culture. However, the lipid content of the control group (group C) was recorded as the lowest. A significant difference ($P<0.05$) was observed between the control group and 625 mg L^{-1} (group B) of AMPEP concentration added to *Chlorella* sp. culture.

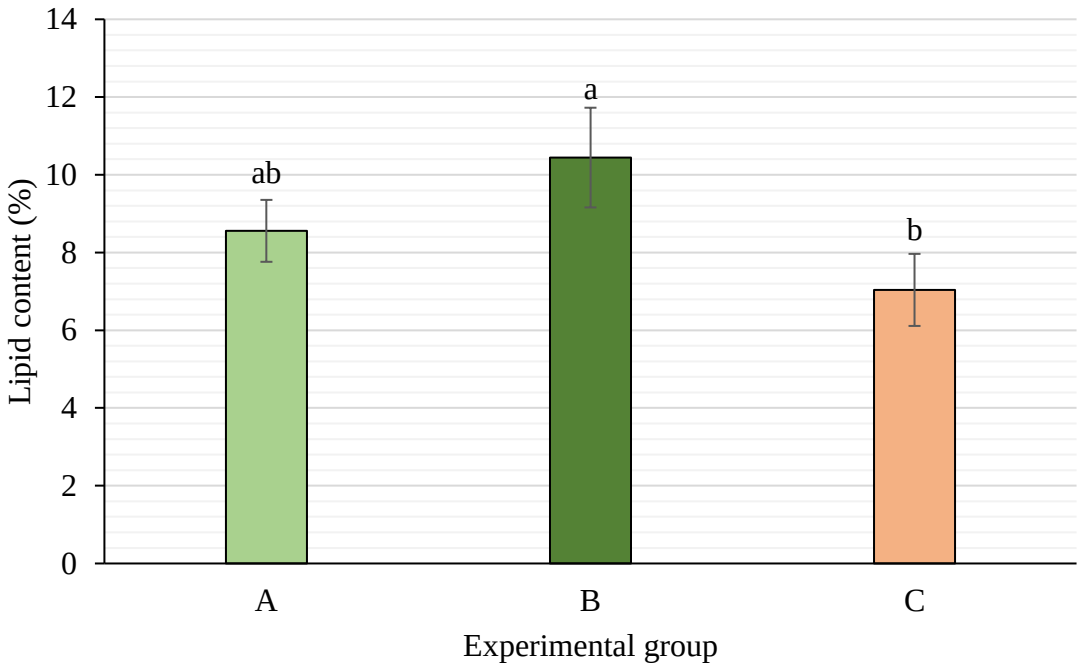

Figure 4- Lipid content (%) of *Chlorella* sp. culture at different concentrations of AMPEP. Group A (125 mg L^{-1}), group B (625 mg L^{-1}), and group C (Control). Differences in the letters are significantly different ($P<0.05$). Mean error bars are in STD (standard deviation), n=9.

4. Discussion

Many crops and horticulture plants have been successfully treated with seaweed extracts to alleviate biotic and abiotic stress (Hurtado & Critchley 2018). An extract from the brown macroalga *A. nodosum* known as *Ascophyllum* (Acadian) Marine Plant Extract Powder (AMPEP) is widely used to increase the performance of crops and horticulture plants, as well as to enhance macroalgae growth such as seaweeds (Silva et al. 2019; Umanzor et al. 2019; Tahiluddin et al. 2022). The present study investigates the use of AMPEP in microalga *Chlorella* sp. culture. According to the results of this study, AMPEP addition to the culture medium of *Chlorella* sp. culture provides higher cell densities. The lower concentration of AMPEP (125 mg L^{-1}) reached higher cell density than groups B and C. It is thought that the brownish color of AMPEP might be reducing the light transmittance, which could be the reason for the difference in growth parameters between AMPEP groups.

To date, various organic and inorganic promoters have been used in microalgae culture, and it has been determined that they induce improvements in culture parameters. For instance, the use of myo-inositol with 500 mg L^{-1} concentration in the *Nannochloropsis oculata* culture resulted in 1.28 fold cells per mL than the control group (Erbil et al. 2020). Another study found that adding 500 mg L^{-1} of myo-inositol to the microalga *Dunaliella salina* culture led to an increase of 1.4-fold cell mL^{-1} over the control group (Cho et al. 2015). Many studies have been conducted on microalgae that grow well in different culture media. Using different phosphate concentrations in a nutrient medium on a *Chlorella vulgaris* culture, a cell number of 2.38 x 106 cells mL^{-1} was obtained (Chia et al. 2013). Additionally, the effect of the phosphate source in an F/2 medium reached a cell number of 32 × 106 cell mL^{-1} on *Chlorella* sp. culture (Aziz & Siti Mariam 2016). Moreover, a study conducted by Durmaz et al. (2007) determined that microalga *Nannochloropsis oculata* could use NO^{-3} as its sole nitrogen source and obtained a maximum cell density of 52 ± 0.3 x 106 cell mL^{-1}. Our results revealed that the lower concentration of AMPEP in a culture medium positively increased the cell density of the *Chlorella* sp. culture.

A general approach to determining growth-limiting substances in cell cultures involves determining their specific growth rate (SGR). One of the factors that can influence microalgae growth is nutrient availability (Jaiswal et al. 2020). In the present study, a lower concentration (125 mg L^{-1}) of AMPEP in a nutrient medium obtained a maximum SGR of 0.60 day^{-1} of *Chlorella* sp. culture. As reported by Liu et al. (2021), phosphate and iron sources in a nutrient medium produced an SGR of 0.286 day^{-1} in the growth of *Chlorella vulgaris* culture, which is lower than the present study such as in the experimental group A (125 mg L^{-1}). Additionally, the SGR of all experimental groups in the present study was higher than the study of Erbil et al. (2021), which examined the production of *Chlorella* sp. culture utilizing BG-11 medium and obtained an SGR of 0.078 day^{-1}. Hence, using BG-11 medium with the addition of AMPEP increased the SGR of *Chlorella* sp. culture.

The yield of *Chlorella* cells cultured with AMPEP was estimated by measuring *Chlorella* biomass after 21 days of cultivation. In the present study, there significant differences were observed among the experimental group, of which the lower concentration of AMPEM (125 mg L^{-1}) produced a higher dry weight of 2.57 g L^{-1} than the dry weight of a higher concentration of AMPEP (625 mg L^{-1}) and the control group. There was a significant amount of dry weight generated in the present study compared to the amount of algae in open raceway ponds, which usually ranges between 0.1 and 0.5 g L^{-1} but can reach up to 1.4 g L^{-1} (Ketheesan & Nirmalakhandan 2012; Ashokkumar et al. 2014; Kumar et al. 2015; Zhu 2015). The present study was comparable to other researchers, which cultured microalga *Nannochloropsis oculata* on fiberglass reinforced plastic panel photobioreactor enriched with f/2 medium and achieved a dry weight of 0.81 g L^{-1} (Durmaz & Erbil 2020). In another study, it was reported that the productivity of continuous cultures enriched with f/2 medium reached 2.02 and 3.03 g L^{-1} at helical tubular photobioreactors (Briassoulis et al. 2010). The results of their study were comparable to those of the present study, in which lower AMPEP levels in a nutrient medium led to an increase in dry weight in *Chlorella* sp. cultures. Moreover, the present study exceeded the results of Feng et al. (2012), in which *Chlorella zofingiensis* was cultivated on BG-11 medium (enriched with nitrogen and phosphate) and achieved a dry weight of 0.90 g L^{-1}. Thus, using BG-11 medium with the addition of AMPEP increased the dry weight of *Chlorella* sp. culture.

Several factors affect the growth and accumulation of lipids in microalgae, including nutrient concentrations, carbon dioxide aeration, and other sustainability-related factors (Xin et al. 2010). As a result of the present study, the incorporation of AMPEP in the nutrient medium increased the lipid production of *Chlorella* sp. culture. In other study, *Chlorella vulgaris* was cultivated in f/2 medium achieved a lipid content of 7.80% (Liu et al. 2008). Comparatively, it is lower than the present study in which higher and lower concentrations of AMPEP achieved lipid content of 10.44% and 8.56%, respectively. Moreover, studies have shown that nutrient limitations can result in high lipid content but low biomass levels (Liu et al. 2021; Hasnain et al. 2023). Low phosphate concentrations in a BG-11 nutrient medium have shown that it lead to greater lipid accumulation of *Chlorella pyrenoidosa* culture (Rana et al. 2020). In the present study, a high level of AMPEP in a BG-11 medium increased lipid accumulation in *Chlorella* sp. culture. Hence, the presence of AMPEP concentration in a nutrient medium may lead to high levels of lipid accumulation of *Chlorella* sp. culture.

5. Conclusions

Chlorella sp. is very important in aquaculture hatcheries due to its properties (pigments, lipids, cell size, fatty acids, etc.). The present study investigated the use of different concentrations of AMPEP in the production of microalga *Chlorella* sp. culture. As a result of the study, a lower concentration of AMPEP (125 mg L^{-1}) in a nutrient medium significantly improves the growth of *Chlorella* sp. culture. Additionally, both concentrations of AMPEP (125 mg L^{-1} and 625 mg L^{-1}) in a nutrient medium increased the lipid accumulation of *Chlorella* sp. culture. However, this study requires further analysis, such as other biochemical compositions (pigments, fatty acids, proteins, etc.), as well as optimization of AMPEP concentrations in the production of microalga *Chlorella* sp. culture.

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References

Ashokkumar V, Agila E, Sivakumar P, Salam Z, Rengasamy R & Ani F N (2014). Optimization and characterization of biodiesel production from microalgae *Botryococcus* grown at semi-continuous system. *Energy conversion and management* 88: 936-946

Aziz A & Siti Mariam O (2016). Phosphate-induced changes in fatty acid biosynthesis in *Chlorella* sp. KS-MA2 strain. *Journal of Biotechnology, Computational Biology and Bionanotechnology* 97(4): 295-304

Briassoulis D, Panagakis P, Chionidis M, Tzenos D, Lalos A, Tsinos C, Berberidis P & Jacobsen A (2010). An experimental helical-tubular photobioreactor for continuous production of *Nannochloropsis* sp. *Bioresource Technology*, 101(17): 6768-6777

Caporgno M P, Haberkorn I, Böcker L, & Mathys A (2019). Cultivation of *Chlorella protothecoides* under different growth modes and its utilization in oil/water emulsions. *Bioresource technology* 288: 121476

Chia M A, Lombardi A T, Maria da Graça M & Parrish C C (2013). Lipid composition of *Chlorella vulgaris* (Trebouxiophyceae) as a function of different cadmium and phosphate concentrations. *Aquatic Toxicology* 128: 171-182

Cho K, Kim K N, Lim N L, Kim M S, Ha J C, Shin H H, Kim M K, Roh S W, Kim D & Oda T (2015). Enhanced biomass and lipid production by supplement of myo-inositol with oceanic microalga *Dunaliella salina*. *Biomass and Bioenergy* 72: 1-7

Christaki E, Bonos E, & Florou-Paneri P (2015). Innovative microalgae pigments as functional ingredients in nutrition. In *Handbook of marine microalgae* (pp. 233-243). Academic Press.

Di Stasio E, Van Oosten M J, Silletti S, Raimondi G, dell'Aversana E, Carillo P, & Maggio A (2018). *Ascophyllum nodosum*-based algal extracts act as enhancers of growth, fruit quality, and adaptation to stress in salinized tomato plants. *Journal of applied Phycology* 30: 2675-2686

Durmaz Y (2007). Vitamin E (α-tocopherol) production by the marine microalgae *Nannochloropsis oculata* (Eustigmatophyceae) in nitrogen limitation. *Aquaculture* 272(1-4): 717-722

Durmaz Y & Erbil G Ç (2020). Comparison of industrial-scale tubular photobioreactor to FRP (fiberglass reinforced plastic) panel photobioreactor on outdoor culture of *Nannochloropsis oculata* in the marine hatchery. *Ege Journal of Fisheries & Aquatic Sciences (EgeJFAS)/Su Ürünleri Dergisi* 37(3): 303-308

Durmaz Y, Donato M, Monteiro M, Gouveia L, Nunes M L, Gama Pereira T, Gokpinar S & Bandarra N M (2008). Effect of Temperature on Growth and Biochemical Composition (Sterols, α-tocopherol, Carotenoids, Fatty Acid Profiles) of the Microalga, *Isochrysis galbana*. *The Israeli Journal of Aquaculture – Bamidgeh* 60(3): 188-195

Erbil G Ç & Durmaz Y (2020). Effects of myo-inositol concentration on growth and pigments of *Nannochloropsis oculata* culture. *Ege Journal of Fisheries and Aquatic Sciences* 37(2): 195-199

Erbil G Ç, Durmaz Y & Mahmut E L P (2021). Indoor Growth Performance of *Chlorella* sp. Production at Tubular Photobioreactor. *Menba Kastamonu Üniversitesi Su Ürünleri Fakültesi Dergisi* 7(2): 90-95

Feng P, Deng Z, Fan L & Hu Z (2012). Lipid accumulation and growth characteristics of *Chlorella zofingiensis* under different nitrate and phosphate concentrations. *Journal of bioscience and bioengineering* 114(4): 405-410

George B, Pancha I, Desai,C, Chokshi K, Paliwal C, Ghosh T & Mishra S (2014). Effects of different media composition, light intensity and photoperiod on morphology and physiology of freshwater microalgae *Ankistrodesmus falcatus*–A potential strain for bio-fuel production. *Bioresource Technology* 171: 367-374

Griffiths M J, van Hille R P & Harrison S T (2012). Lipid productivity, settling potential, and fatty acid profile of 11 microalgal species grown under nitrogen-replete and limited conditions. *Journal of Applied Phycology* 24: 989-1001

Hairol M D, Nian C T, Imlani A H, Tikmasan J & Sarri J H (2022). Effects of Crab Shellmeal Inclusions to Fishmeal Replacement on the Survival, Growth, and Feed Utilization of Mangrove Crab *Scylla serrata* (Forsskal 1775). *Yuzuncu Yil University Journal of Agricultural Sciences* 32(4): 714-726

Hasnain M, Abideen Z, Hashmi S, Naz S & Munir N (2023). Assessing the potential of nutrient deficiency for enhancement of biodiesel production in algal resources. *Biofuels* 14(1): 1-34

Hurtado A Q, & Critchley A T (2018). A review of multiple biostimulant and bioeffector benefits of AMPEP, an extract of the brown alga *Ascophyllum nodosum*, as applied to the enhanced cultivation and micropropagation of the commercially important red algal carrageenophyte *Kappaphycus alvarezii* and its selected cultivars. *Journal of Applied Phycology* 30: 2859-2873

Hurtado A Q, Yunque D A, Tibubos K & Critchley A T (2009). Use of Acadian marine plant extract powder from *Ascophyllum nodosum* in tissue culture of Kappaphycus varieties. *Journal of Applied Phycology* 21: 633-639

Islam M A, Magnusson M, Brown R J, Ayoko G A, Nabi M N & Heimann K (2013). Microalgal species selection for biodiesel production based on fuel properties derived from fatty acid profiles. *Energies* 6(11): 5676-5702

Jaiswal K K, Banerjee I, Singh D, Sajwan P & Chhetri V (2020). Ecological stress stimulus to improve microalgae biofuel generation: a review. *Octa Journal of Biosciences* 8: 48-54

Juneja A, Ceballos R M & Murthy G S (2013). Effects of environmental factors and nutrient availability on the biochemical composition of algae for biofuels production: a review. *Energies* 6(9): 4607-4638

Kaparapu J (2018). Application of microalgae in aquaculture. *Phykos* 48(1): 21-26

Ketheesan B & Nirmalakhandan N (2012). Feasibility of microalgal cultivation in a pilot-scale airlift-driven raceway reactor. *Bioresource Technology* 108: 196-202

Khan M I, Shin J H & Kim J D (2018). The promising future of microalgae: current status, challenges, and optimization of a sustainable and renewable industry for biofuels, feed, and other products. *Microbial cell factories* 17(1): 1-21

Khanra S, Mondal M, Halder G, Tiwari O N, Gayen K, & Bhowmick T K (2018). Downstream processing of microalgae for pigments, protein and carbohydrate in industrial application: A review. *Food and bioproducts processing* 110: 60-84

Kumar K S, Dahms H U, Won E J, Lee J S & Shin K H (2015). Microalgae–a promising tool for heavy metal remediation. *Ecotoxicology and environmental safety* 113: 329-352

Liu J, Qiu Y, He L, Luo K & Wang Z (2021). Effect of iron and phosphorus on the microalgae growth in co-culture. *Archives of Microbiology*, 203(2): 733-740

Liu Z Y, Wang G C & Zhou B C (2008). Effect of iron on growth and lipid accumulation in *Chlorella vulgaris*. *Bioresource Technology* 99(11): 4717-4722

Loureiro R R, Hurtado A Q & Critchley A T (2017). Impacts of AMPEP on epiphytes and diseases in *Kappaphycus* and *Eucheuma* cultivation. *Tropical Seaweed Farming Trends, Problems and Opportunities: Focus on Kappaphycus and Eucheuma of Commerce* pp. 111-119

Mishra S K, Suh W I, Farooq W, Moon M, Shrivastav A, Park M S & Yang J W (2014). Rapid quantification of microalgal lipids in aqueous medium by a simple colorimetric method. *Bioresource Technology* 155: 330-333

Montemezzani V, Duggan I C, Hogg I D, & Craggs R J (2015). A review of potential methods for zooplankton control in wastewater treatment High Rate Algal Ponds and algal production raceways. *Algal research* 11: 211-226

Nascimento I A, Marques S S I, Cabanelas I T D, Pereira S A, Druzian J I, de Souza C O, Vich D V, de Carvalho G C, & Nascimento M A (2013). Screening microalgae strains for biodiesel production: lipid productivity and estimation of fuel quality based on fatty acids profiles as selective criteria. *Bioenergy Research* 6: 1-13

Niccolai A, Zittelli G C, Rodolfi L, Biondi N, & Tredici M R (2019). Microalgae of interest as food source: Biochemical composition and digestibility. *Algal Research* 42: 101617

Rahman K M (2020). Food and high value products from microalgae: market opportunities and challenges. *Microalgae Biotechnology for Food, Health and High Value Products* pp. 3-27

Rana M S, Bhushan S & Prajapati S K (2020). New insights on improved growth and biogas production potential of *Chlorella pyrenoidosa* through intermittent iron oxide nanoparticle supplementation. *Scientific Reports* 10(1): 1-13

Rizwan M, Mujtaba G, Memon S A, Lee K & Rashid N (2018). Exploring the potential of microalgae for new biotechnology applications and beyond: a review. *Renewable and Sustainable Energy Reviews* 92: 394-404

Sanuddin N B, Hairol M D, Nian C T, Robles R J F, Illud H A, Muyong J S, Ebbah J H & Sarri J H (2023). Impact of Different Nutrient Enrichment Concentrations on the Growth of Microalga *Nannochloropsis* sp. (Monodopsidaceae) Culture. *Acta Natura & Scientia* 4(1)

Shukla P S, Mantin E G, Adil M, Bajpai S, Critchley A T & Prithiviraj B (2019). *Ascophyllum nodosum*-based biostimulants: Sustainable applications in agriculture for the stimulation of plant growth, stress tolerance, and disease management. *Frontiers in plant science* 10: 655

Silva L D, Bahcevandziev K, & Pereira L (2019). Production of bio-fertilizer from *Ascophyllum nodosum* and *Sargassum muticum* (Phaeophyceae). *Journal of Oceanology and Limnology* 37: 918-927

Silva S C, Ferreira I C, Dias M M, & Barreiro M F (2020). Microalgae-derived pigments: A 10-year bibliometric review and industry and market trend analysis. *Molecules* 25(15): 3406

Sulochana S B & Arumugam M (2020). Targeted metabolomic and biochemical changes during nitrogen stress mediated lipid accumulation in *Scenedesmus quadricauda* CASA CC202. *Frontiers in Bioengineering and Biotechnology* 8: 585632

Tahiluddin A B, Andon A & Burahim M (2022). Effects of Acadian Marine Plant Extract Powder (AMPEP) and ammonium phosphate as Nutrient Enrichment on the ice-ice disease occurrence and growth performance of Seaweed *Kappaphycus striatus*. Mediterranean Fisheries and Aquaculture Research 5(2): 37-46

Tayemeh M B, Esmailbeigi M, Shirdel I, Joo H S, Johari S A, Banan A, Nourani H, Mashhadi H, Jami M J & Tabarrok M (2020). Perturbation of fatty acid composition, pigments, and growth indices of Chlorella vulgaris in response to silver ions and nanoparticles: A new holistic understanding of hidden ecotoxicological aspect of pollutants. *Chemosphere* 238: 124576

Udayan A, Pandey A K, Sirohi R, Sreekumar N, Sang B I, Sim S J, Kim S H & Pandey A (2023). Production of microalgae with high lipid content and their potential as sources of nutraceuticals. *Phytochemistry Reviews* pp. 833-860

Umanzor S, Shin S, Marty-Rivera M, Augyte S, Yarish C & Kim J K (2019). Preliminary assessment on the effects of the commercial seaweed extract, AMPEP, on growth and thermal tolerance of the kelp *Saccharina* spp. from the Northwest Atlantic. *Journal of Applied Phycology* 31: 3823-3829

Vismara R, Vestri S, Kusmic C, Barsanti L & Gualtieri P (2003). Natural vitamin E enrichment of *Artemia salina* fed freshwater and marine microalgae. *Journal of Applied Phycology* 15(1): 75-80

Wahidin S, Idris A & Shaleh S R M (2013). The influence of light intensity and photoperiod on the growth and lipid content of microalgae *Nannochloropsis* sp. *Bioresource Technology* 129: 7-11

Xin L, Hong-Ying H, Ke G & Ying-Xue S (2010). Effects of different nitrogen and phosphorus concentrations on the growth, nutrient uptake, and lipid accumulation of a freshwater microalga *Scenedesmus* sp. *Bioresource Technology* 101(14): 5494-5500

Zhu L (2015). Biorefinery as a promising approach to promote microalgae industry: An innovative framework. *Renewable and Sustainable Energy Reviews* 41: 1376-1384

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Effects of PGPB Inoculations on Plant Growth and Quality of Spray Carnation Cultivation in Greenhouse

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ABSTRACT

In order to achieve the desired quality characteristics and good growth in ornamental plants, various applications are carried out. Recently, the importance of beneficial bacteria, which play an extremely important role in sustainable ecology and are environmentally friendly, has been increasingly recognized. However, the effect of beneficial bacteria, which are not sufficiently applied in ornamental plants as well as in other plant groups, on the growth and quality characteristics of spray carnation variety, which is the most preferred among cut flowers, was investigated in this study.

In the greenhouse, the carnation seedlings were treated with *Enterobacter ludwigii* (KF29A), *Pseudomonas fluorescens* (KF31B), *Paenarthrobacter nitroguaiacolicus* (KF3B), *Pseudomonas* sp. strain VG242B (KF5A), *Paenibacillus xylanilyticus* (KF63C), *Pseudoalteromonas tetraodonis* (TV126C) bacteria which have been selected according to nitrogen fixation, phosphate solubilizing, ACC deaminase and siderophore production properties were applied. In the study, in which phenological and morphological observations were made, the effects of bacterial inoculations were tried to be determined.

The effects of beneficial bacteria treatments on the number of petals, the number of nodes, the length between the nodes and the weight of the branches in the carnation plant were statistically insignificant; effects on the parameters of bud first bloom time, full bloom time, time from planting to first harvest, number of flower buds and stem length ($P<0.01$), flower (diameter) width and stem thickness ($P<0.05$) was found to be statistically significant. First bud bloom, full bloom and time from planting to first harvest are 103.38 days, 103.74 days and 106.28 days (KF63C) respectively, maximum number of flower buds is 4.77 (TV126C), flower diameter is 46.73 mm at the widest (KF63C), the highest stem thickness was 3.39 cm (KF3B) and the highest stem length was 56.33 cm (TV126C).

The first flowering time of the buds appeared with a delay of approximately 10-30 days compared to the control with bacterial applications. It is seen that bacterial applications cause an increase on flower stem thickness, flower stem length, flower bud and petal number.

Keywords: Bacteria, Flowering, *Dianthus caryophyllus*, Quality criteria, PGPB

1. Introduction

Cut flower production is one of the sub-group of ornamental plant production activities. It is important in terms of production volume and economic value. Cut flower cultivation began to gain importance worldwide in the 20th century. The most traded cut flower species in the world are roses, chrysanthemums and carnations, respectively. Carnation (*Dianthus caryophyllus* L.), one of the most popular commercial cut flowers in the World and is preferred by many exporting countries due to its wide range of forms and colors, excellent preservation quality and resistance to long-distance transportation (Kumar 2021). Carnation, which is the subject of research, has a very important place in cut flower cultivation and its commercial production is intense. Carnation (*Dianthus caryophyllus* L.) is a species in the Caryophyllaceae (Carnations) family and in the genus *Dianthus* is native to the Mediterranean Region (Besemer 1980; Whealy & Larson 1992). According to Alkaç et al. (2023), the worldwide export of carnation, which is among the most produced cut flowers, was worth 227 million Euros in 2018 (AIPH 2019), and as of 2019, its production is about 635 million in a greenhouse area of 5 thousand decares (TUIK, 2020). Türkiye also made significant contributions to the export of this plant species and ranked 3rd in world carnation exports after the Netherlands and Colombia.
Cut flower production and trade constitute the most important group in the ornamental plants sector in Türkiye, as well as in the World. According to 2022 data in Türkiye, the provinces with the highest production of cut flowers are Antalya (6030.2 da), İzmir (3349.9 da), Isparta (1815.0 da) and Yalova (835.1 da). Carnation production is mostly done in Antalya and İzmir (TUİK 2022).

Table 1- Production amount (units) of the most important cut flower species traded in Türkiye by years

Species/Product Groups	***Production quantity (units)***				***% Share (2022)***	***(2017-21) (%) Rate of Change***	***(2021-22) (%)Rate of Change***
	2017	***2019***	***2021***	***2022***			
Carnation	593 097 350	635 157 850	606 841 140	986 298 552	70.2	9.47	62.5
Gerbera	127 206 050	134 481 050	120 603 008	70 893 208	5.0	-5.2	-11.2
Cut Rose	107 942 520	98 130 020	101 204 410	99 417 885	7.1	-5.1	-1.8
Chrysanthemum	44 476.525	47 677 050	78 649 425	84 133 160	6.0	76.8	7.0
Freesia	17 815 150	17 463 650	11 339 400	14 434 160	1.0	-36.4	27.3
Tulip	44 504 500	40 290 500	27 830 000	4 930 000	0.3	-37.5	-82.3
Solidago	18 968 500	17 386 400	24 595 600	14 186 000	1.0	29.6	-42.3
Lisiantus	13 003 000	12 808 100	20 346 800	14 978 100	1.1	56.0	-26.4
Gypsophila	18 355 290	18 105 690	19 550 940	41 908 240	3.0	6.5	114.4
Narcissus	13 810 250	14 832 000	10 515 000	26 510 000	1.3	-23.9	152.1
Lily	9 552 285	9 282 685	7 916 525	8 806 025	0.6	-17.12	2.1
Matthiola	6 412 940	6 777 238	7 412 290	8 645 290	0.5	15.6	16.6
Gladiolus	7 269 800	6 709 900	4 824 900	5 427 900	0.3	-23.86	12.5
Orchid	1 624 940	1 885 930	1 903 800	2 870 300	0.2	17.16	50.8
Limonium	141 000	133 000	714 350	714 350	0.1	406	0.0
Others	29 107 560	32 212 880	20 735 366	21 037 175	1.6	-28.9	1.01
Total	**1 050 584 960**	**1 093 333 943**	**1 064 982 954**	**1 404 473 345**	**100 0**	**5.63**	**31.4**

(TUİK 2019; 2021; 2022)

When the amount of cut flower production in Türkiye between 2017 and 2021 is examined, it is seen that carnation (986 298 552 pieces) ranks first (Table 1) (TUİK 2021; 2022). Among these, spray carnation emerges as the main product for many cut flower exports.

According to TUİK 2023 data, Türkiye produces carnations in 6 020.87 da of the 58 146.01 da cut flower production area and exports almost all of the carnations produced (TUİK 2023). The prominent province in carnation production and export in Türkiye is Antalya, and its climatic conditions allow production and export for nine months, from the beginning of September to the end of May.

In Antalya, rainfall in the form of torrential downpours can sometimes negatively affect production. The months when production intensifies and the period of maximum rainfall are largely parallel. Rainwater, which is difficult to drain from greenhouses in some enterprises, causes the disease called black spot on flowers. This leads to a significant decrease in the quality of these export-oriented products (Zaman et al. 2011).

Fusarium sp., *Macrophomina* sp., *Rhizoctonia* sp., *Pythium* sp., *Verticillium* sp., *Alternaria* spp., *Sordaria* spp., *Aspergillus* spp., *Penicillium* spp. and *Trichoderma* spp. fungus species were identified in samples taken from plants showing signs of disease in carnation greenhouses in Antalya province (Atakan & Özgönen Özkaya 2018). These soil-borne fungi also cause quality loss in plants. *Fusarium* spp., *Rhizoctonia solani, Pythium* spp. can occur at any time during the production season and cause significant plant losses in greenhouses by causing seedling drying, wilt, root and stem rot in the early post-planting period (McCain 2003; Şevik & Saruhan 2010). Red spider, thrips and greenworm are the main pests of carnations and the most important pest in Antalya province is *Frankliniella occidentalis* (Pergande) (Thysanopiera, Thripidae) (Tunç & Göçmen 1995). This pest sucks plant sap and forms typical white spots on the petals of carnation flowers (Keçeçioğlu 2001). Keçecioğlu & Madanlar (2002) examined the effects of insecticides used with different applications on *F. occidentalis* in a greenhouse in the region. In the study carried out to determine the fertility status of greenhouse soils where carnation are grown in Kepez district of Antalya province, it was determined that the textures of the greenhouse soils ranged from sandy to clayey, pH was generally alkaline and slightly alkaline reaction, and electrical conductivity values varied from non-saline to very high saline. The majority of the soils contain excessive lime and are humus poor in terms of organic matter content. Total N and exchangeable K contents vary from very low to very good, while the amount of available P is adequate and exchangeable Mg and Ca are good (Asri Öktüren et al. 2016). Asri Öktüren et al. (2016) pointed out that nutritional problems that may arise from the antagonistic effect between plant nutrients will be reduced if the producers adjust the pH of the nutrient solutions they use between 6.5-7.0, considering that the clove plant prefers slightly acid and neutral conditions, and recommended that priority should be given to practices aimed at increasing the level of organic matter in the soil in order to eliminate this negative effect that may arise in greenhouse soils, and organic origin fertilizers should be used as much as possible in the fertilization programs to be applied. The researchers stated that although nitrogen fertilizer in chemical form is generally used in greenhouses, 68% of the clove greenhouses examined had low nitrogen content, and this may be due to the high uptake and washing in the form of NO_3^-. In conclusion, in order to increase the quality and yield in carnation cultivation, which has an important place in exports, fertilization programs suitable for soil characteristics should be developed and unbalanced and unconscious fertilization practices should be avoided.

Chemical fertilizers play an important role in increasing production. However, excessive use of chemical fertilizers causes soil fertility to be lost and deteriorated. Theoretically, a significant increase in yield cannot be achieved with high-use artificial fertilizers. It is known that chemical fertilizers harm the environment. Research, advancement and adaptation of biological substitutes have brought the importance and acceptance of organic fertilizers to the agenda. Today, worldwide researches are carried out to create organic fertilizer formulations for clean living spaces and healthy production (Çakmakçı 2005). There is an increasing trend towards organic fertilizers to eliminate the negative effects of chemical fertilizer use all over the world. Among organic fertilizers, plant growth-promoting bacteria (PGPB) are used as raw materials for microbial fertilizers (Meena & Rai 2017). Bacteria constitute the largest part of microorganisms living in the soil. Research has shown that some bacteria support plant development in many ways with different mechanisms of action. These beneficial bacteria were named PGPR (Plant Growth Promoting Rhizobacteria) (Kloepper et al. 1980). They are also known as "Probiotic Rhizobacteria" due to the many benefits they provide to the plant (Ram et al. 2013). PGPRs promote plant development with their action mechanisms such as nitrogen fixation, solubilizing phosphorus and heavy metals, producing hormones, increasing water and mineral uptake, supporting root development, and increasing enzyme activity in the plant. Many researchers are conducting research on the wide range of uses of rhizobacteria. Research has shown that rhizobacteria are responsible for detoxification of heavy metals (Wani & Khan 2010), degradation of pesticides (Ahemad & Khan 2012), salinity tolerance (Mayak et al. 2004), biological control of plant diseases and pests (Hynes et al. 2008; Tozlu et al. 2012), increasing the use of nutrients and minerals by the plant (Çakmakcı 2009), supporting plant development by producing phytohormones and enzymes (Dejordjevic et al. 1987; Ferreira et al. 1987).

Root bacteria (Plant Growth Promoting Rhizobacteria- PGPR), which increase plant growth, have an important place because they increase plant growth and yield (Gül et al. 2008; Çelik et al. 2020). In recent years, it is seen that bacteria that promote plant growth are widely used in fruit and vegetable species that are difficult to root and produce, and in some field crops, while their use in ornamental plants is quite limited.

Sezen & Külekçi (2020) used ornamental plants that are difficult to produce as materials and bacteria that affect the growth parameters of ornamental plants and promote growth. As a result of the research, ornamental plants, and applied bacteria were explained, and the importance of disseminating the use of naturally sourced bacteria that do not harm the environment and support the development of ornamental plants was emphasized.

The colour, height, flower size, yield and growth rate of the varieties vary according to their resistance to diseases, and stress conditions such as cold and heat, salinity and heavy metals. That's why growing and care conditions are very important. Ultimately, the market value of flowers is determined by these factors. The desired level of flowers and quality increases the market value of carnations. Similar to other researchers, it would be logical to investigate the effects of beneficial bacteria on carnation, the most preferred cut flower variety in Türkiye, and to determine the benefits it will provide in its production.

In this context, this study is important in terms of revealing how bacterial applications as biological fertilization affect carnation flowers and accordingly changes in plant and flower quality.

2. Material and Methods

2.1. Materials

2.1.1. Plant material

The carnation seedlings used as material were produced from cuttings taken from fast growing and white colored spray carnation plants grown in the greenhouse (Figure 1).

Figure 1- White-colored spray carnation

2.1.2. Bacteria strains

The bacteria used in the study were obtained from the Department of Field Crops, Faculty of Agriculture, Siirt University. Bacterial isolates are isolates from the rhizospheres of Lake Van Basin (TV group) (Erman et al. 2010) and Siirt province (KF group) within the scope of TOVAG 108O147 TUBITAK project in Türkiye and previously diagnosed with MIS system and Plant Growth Promoting Bacteria (PGPB) activity has been demonstrated in field and greenhouse conditions. These bacterial strains were selected according to their strong or weak effects on nitrogen fixation, phosphate solubilizing, ACC deaminase, and siderophore production (Table 2).

Table 2- Bacterial strains inoculated into the soil and their characteristics

Bacteria Code	***Nitrogen Fixation***	***Phosphate Solubilizing***	***ACC Deaminase***	***Siderophore Production***
Control (no bacteria applied)				
KF3B *Paenarthrobacter nitroguajacolicus*	+	-	+++	+
KF5A *Pseudomonas* sp. strain VG242B	+	++	-	+
KF29A *Enterobacter ludwigii*	+	++	-	+
KF31B *Pseudomonas fluorescens*	+	++	-	+
KF63C *Paenibacillus xylanilyticus*	+	++	++	+
TV126C *Pseudoalteromonas tetraodonis*	Strong	Weak	+	-

2.1.3. Properties of the experimental area

This study was carried out in the 8-decare greenhouse of a private enterprise called Flora City in Aksu district of Antalya, covered with polyethylene and made of iron construction. The area where the study was carried out is at an altitude of 581 meters, at 36° 58' 24" N and 30° 48' 49" E coordinates (Figure 2).

Figure 2- The greenhouse where the experiment was conducted (Google Earth 2023)

3. Methods

3.1. Cultivation of carnation seedlings

The first step before planting clove cuttings in the greenhouse is rooting them with indole butyric acid (IBA) (Figure 3). Cuttings treated with IBA were transplanted into a rooting medium consisting of a mixture of half peat and perlite (Figure 4). When the cuttings started to develop, nitrogen fertilization was applied twice a week to increase the height of the plant. In addition, spraying was done every two days to combat red spider and root rot (active substance: abamectin) and (active substance: tolclofosmethyl). The rooted cuttings (Figure 5) were placed in mulch bags of at least 25, pre-cooled, and then placed in cold storage with 80-85% humidity and 2-4 °C temperature (Figure 6). Then, the carnation seedlings were planted 25 cm apart under a clean and sterilized greenhouse (Figure 7). A trellis system was built in the planting area and meshes were woven row spcae and on the rows. After planting, tip removal was done twice and harvesting was done considering gradation.

Figure 3- IBA treatment of carnation seedlings

Figure 4- Planting of carnation seedlings on tables

Figure 5- Rooted carnation cuttings

Figure 6- Carnation seedlings placed in cold storage

Figure 7- Planting of seedlings

Figure 8- Bacterial contamination of carnation seedlings

3.2. Preparation of stocks of ınoculated bacterial strains

Nutrient agar (Merck-VM71680604) was used as a solid medium for the propagation and production of bacteria. The pH was adjusted to 7.0 by adding 20 g of nutrient agar to one liter of distilled water and the mixture was sterilized by autoclave at 121 °C for 15 minutes. After sterilization, the media were cooled to 50 °C, transferred to Petri dishes, and left to solidify. Stock cultures of bacteria were inoculated on a nutrient agar medium with a loop and incubated for 24 hours at 26 ± 2 °C.

Nutrient broth (Merck-VM775843711) was used as broth. The pH was adjusted to 7.0 by adding 8 g of nutrient broth medium to one liter of distilled water. The mixture was sterilized by autoclave at 121 °C for 15 minutes and left to cool. A single colony was taken from bacteria grown on Nutrient agar medium and transferred to nutrient broth medium under aseptic conditions. Bacteria transferred to the broth were incubated at 26 ± 2 °C for 24 hours and at 120 rpm in a horizontal shaker. After incubation, bacterial concentrations were turbidimetrically adjusted to ~108 cfu/mL.

After shaking overnight and ensuring homogeneity, 10 mL was inoculated into the soil from the root collar in the area where the carnations were planted (Figure 8).

After this first inoculation, the second inoculation was made just before the time of flower bud emergence and in the same amount.

To compare with the effect of bacterial strains, a control group was also formed, and in carnations that were not contaminated with bacteria and in carnations inoculated with bacteria, flower stalk length, number of nodes, the length between internodes, flower stalk thickness, branch weight, flower diameter, flower bud (bud) number, petal measurements, and observations were made on the number of petals, bud first bloom time, full bloom time and the time from planting to first harvest.

3.3. Experimental plan and statistical analysis

The study was conducted according to a randomized plots experimental design and consisted of a control group with no treatment and treatments consisting of inoculation of 6 bacterial strains. Each treatment group consisted of 3 replicates and 15 carnation seedlings were used in each replicate. The data were analysed in the SAS For Academics on Demand Online Statistics package program. Means were compared using Duncan's multiple comparison tests for traits in which the difference between treatments was significant. The tests were performed at the α=0.05 significance level (Düzgünes et al. 1987).

4. Results and Discussion

The effects of beneficial bacteria on the development and flowering of the carnation plant are given in Table 3.

Table 3- The effects of bacterial strains on the development and flowering of the carnation plant

Applications	*Bud's first bloom time (days)***	*Full bloom time (days)***	*Time from planting to first harvest (days)***	*Number of flower buds (pieces)***	*Number of petals (pcs) ns*	*Flower diameter (mm)**	*Node number (piece) ns*	*Internode length (cm)ns*	*Petiole thickness (mm)**	*Flower stem length (cm)***	*Branch weight (g) ns*
Control	118.42 bc	120.07 bc	121.62 bc	3.91 b	48.73	43.84 ab	9.42	5.48	3.01 ab	50.86 bc	31.95
KF29A	129.86 ab	131.51 b	134.10 ab	4.44 ab	54.44	38.16 b	8.91	5.80	3.27 ab	53.31 ab	31.99
KF31B	131.35 ab	132.69 b	133.90 ab	4.38 ab	50.62	44.41 ab	9.57	5.41	3.01 ab	51.03 bc	30.01
KF3B	127.71 ab	132.91 b	139.42 ab	4.31 ab	45.00	43.40 ab	9.13	4.77	3.39 a	44.97 d	31.77
KF5A	147.60 a	152.97 a	154.67 a	3.66 b	49.66	46.32 a	9.18	6.23	3.17 ab	47.93 cd	29.51
KF63C	103.38 c	103.74 c	106.28 c	3.84 b	47.02	46.73 a	9.20	5.62	2.72 b	49.54 bcd	34.74
TV126C	135.68 ab	137.13 ab	139.55 ab	4.77 a	51.80	42.32 ab	9.82	5.60	3.13 ab	56.33 a	32.98
F values	11.06	15.47	9.80	5.28	2.63	3.81	2.16	1.25	3.07	13.91	0.80

KF29A: *Enterobacter ludwigii*; KF31B: *Pseudomanas fluorescens*; KF3B: *Paenarthrobacter nitroguaiacolicus*; KF5A: *Pseudomonas* sp. Strain VG242B; KF63C: *Paenibacillus xylanilyticus*; TV126C: *Pseudoalteromonas tetraodonis*
ns: no significant, *: significant at 5%, **: significant at 1%

The differences between the averages denoted by the same letter in the same column are not significant.

4.1. Bud's first bloom time (days)

The effects of beneficial bacteria applications on the first flowering period of the carnation plant were found to be statistically significant at the P<0.01 level. The earliest bud opening time was observed in the application of KF63C bacteria (103.38 days), and the latest bud opening time (147.6 days) was obtained in the application of KF5A bacteria (Figure 9). The buds of the control group carnations bloomed for the first time in 118.42 days. Control buds bloomed up to 15 days later than some KF63C bacteria-inoculated carnations. Earlier blooming between 9-29 days than other bacterial treatments showed that bacterial strains affected the flowering times. As it is known, phosphorus is an element that affects flowering in plants. As seen in the results obtained in the research, the application of KF63C bacteria, which has a versatile effect, had a greater effect than other bacteria and the control application and provided the earliest flowering on the plant (Ali et al. 2012; Gunjal & Glick 2023). The application of KF63C bacteria has produced a very important result, especially in terms of early flowering, bringing the product to the market early and selling it at a higher price.

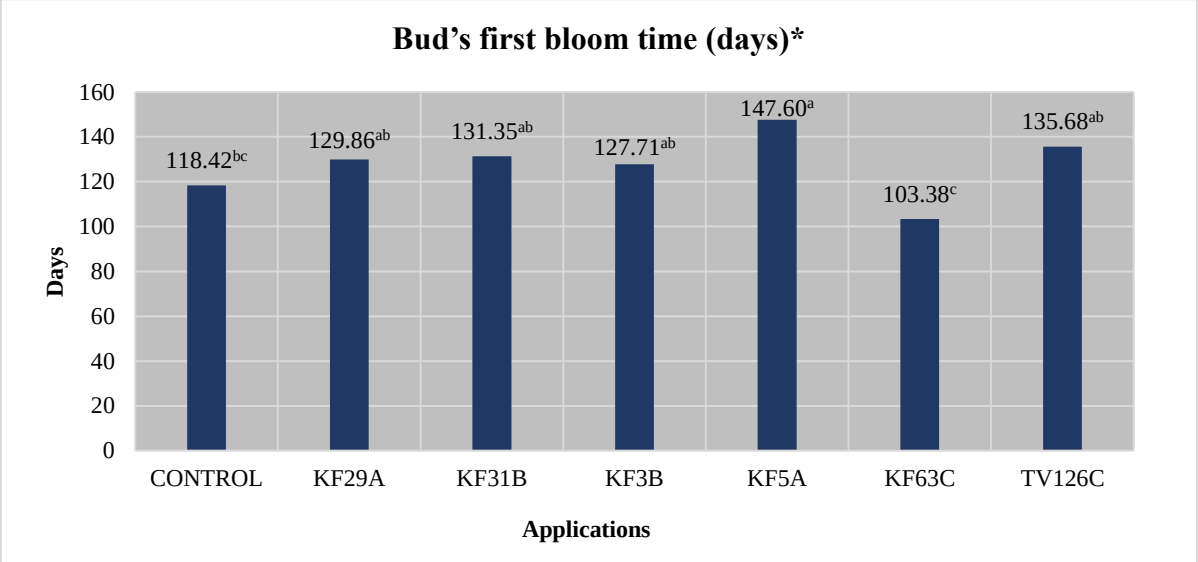

Figure 9- Time taken for the first flowering of carnation buds (days), *: The differences between applications statistically are significant at P<0.01

4.2. Full Bloom time (days)

The effects of beneficial bacteria applications on the full flowering period of the carnation plant were found to be statistically significant (P<0.01). The earliest full flowering period (103.74 days) was observed in the application of KF63C bacteria, and the latest full flowering period (152.97 days) was reached with the application of KF5A bacteria (Figure 10). The data obtained showed parallelism with the first blooming times of the buds. Control carnations reached full bloom in a longer time than carnations inoculated with only KF63C bacteria and reached this stage in a shorter time than carnations treated with other bacteria.

Phosphorus is an element that affects flowering in plants. As seen in the results obtained in the research, in the application of KF5A bacteria, the phosphate solubilization feature showed more effect than other bacteria and caused the full flowering time at the latest. In flower production, late production is as important as early production in terms of market advantage. Especially as the amount of product offered decreases, product prices increase. For this reason, it is thought that the application of KF5A bacteria may cause late full flowering, resulting in product supply at high prices and therefore high economic returns. Flower supply to the market late in cold storage etc. Providing it by taking precautions is very difficult and costly due to energy, storage space, labor and other reasons (Güneş & Babadağ 2022).

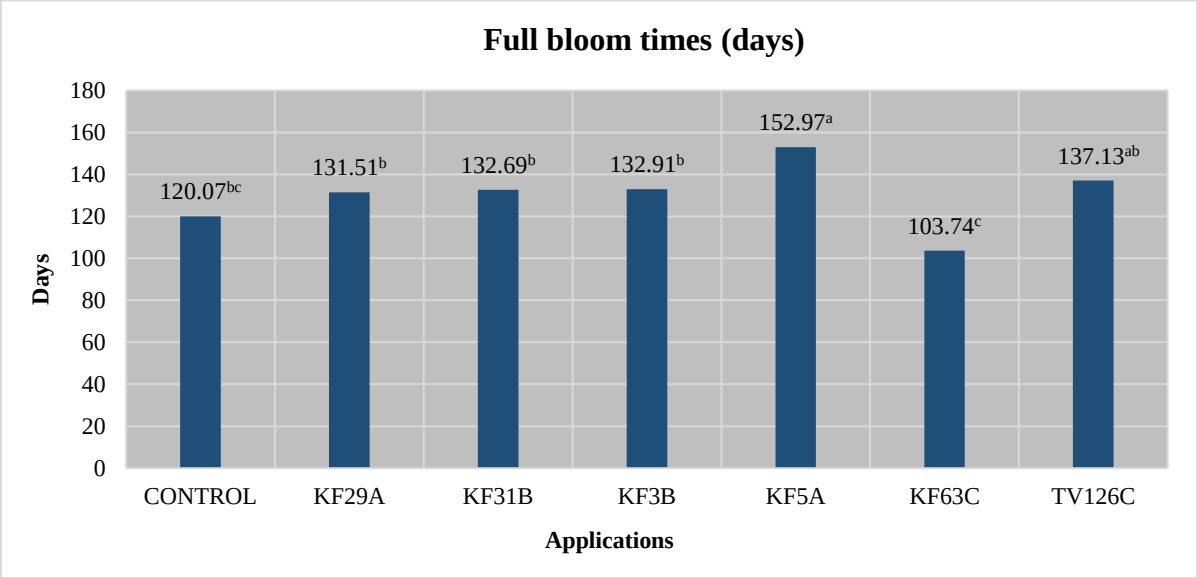

Figure 10- Time taken for full bloom of carnation buds (days), *: The differences between applications statistically are significant at P<0.01

4.3. Time from planting to first harvest (days)

The effects of bacteria applications on the period from planting to harvest in the carnation plant were found to be statistically significant (P<0.01). The time from planting to the first harvest was reached by the application of KF63C at the earliest (106.28 days) and at the latest (154.67 days) with the application of KF5A bacteria (Figure 11). Most of the bacteria applied in our study with carnations caused a delay in harvest time. Of these, only one strain of bacteria (KF63C) provided 15 days of earliness compared to the control group. While KF29A, KF31B, and KF3B bacterial strains caused the flowers to be harvested at almost the same time, TV126C bacterial strain was effective in the harvest for approximately 5 days after these three strains.

In terms of the effect of planting time on the first harvest time, the earliest harvest time among the applications was obtained from the application of KF63C bacteria, which has versatile properties. This result reveals that bacteria with versatile properties are more advantageous in terms of their mechanism of action than bacteria that have a unidirectional effect or have a weak effect in terms of some properties (Çığ et al. 2017; Glick 2020).

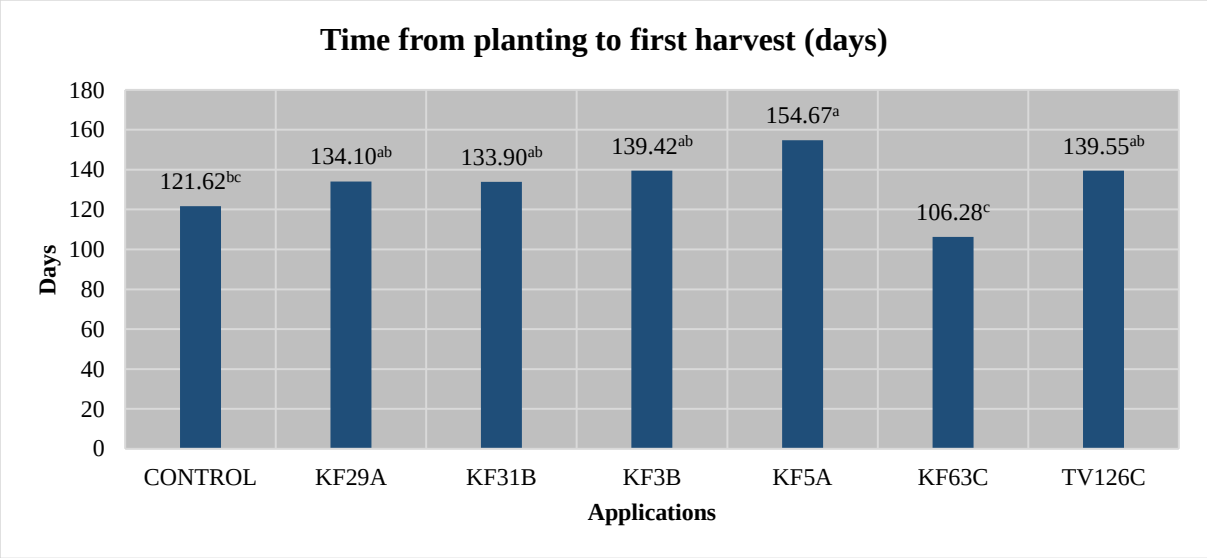

Figure 11- Time spent by carnation seedlings from planting to harvest (days), *: The differences between applications statistically are significant at P<0.01

4.4. Number of flower buds (pieces)

The effects of beneficial bacteria applications on the number of flower buds in carnation were found to be statistically significant (P<0.01). The highest number of flower buds (4.77 pieces) was seen with the application of TV126C bacteria, and the lowest number of flower buds (3.66 units) was reached with the application of KF5A bacteria (Figure 12). The number of buds in the control group carnations was determined as 3.91, and it was observed that this number was more bud formation than the carnations in which KF5A and KF63C bacterial strains were inoculated.

In terms of the number of flower buds, lower values were obtained in KF5A and KF63C applications compared to the control. Although quantitatively lower values are obtained in bacterial inoculations, qualitatively higher quality flower formation can be observed (Ali et al. 2012; Gunjal & Glick 2023). However, obtaining higher values in other bacterial applications compared to the control showed that alternative bacterial strains can be used in cultivation. This data also showed that different properties of bacteria can be used to serve different purposes (Glick 2020).

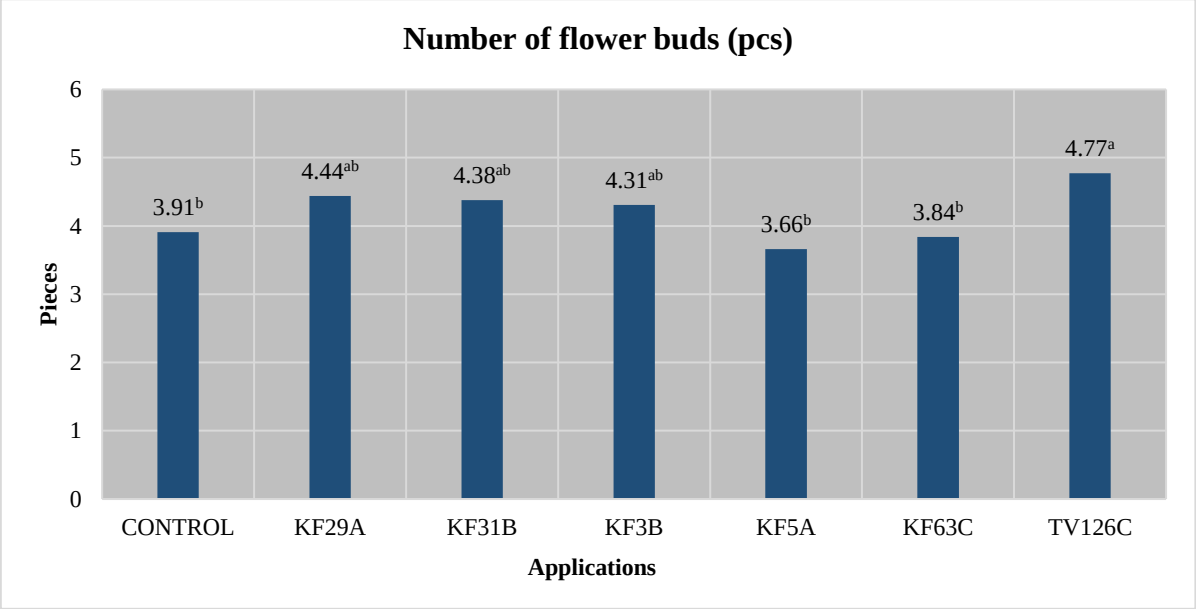

Figure12- The number of flower buds on the carnation plant (pieces), *: The differences between applications statistically are significant at P<0.01

4.5. Number of petals (pieces)

The effects of bacterial applications on the number of petals in the carnation plant were found to be statistically insignificant (Figure 13). The highest number of petals (54.44 units) was observed in the application of KF29A bacteria, and the lowest value of the number of petals (45 units) was obtained in the inoculation of KF3B bacteria. The number of petals in the flowers of the carnations grown in the control group was found to be higher than that of the carnations inoculated with KF63C and KF3B bacteria, and lower than those of other applications. The fullness of the flowers causes the carnations to be showier. Therefore, the difference in the lowest and highest number of petals is important for the showiness of the flowers.

It is thought that the KF29A bacteria, which has a strong phosphate solubilizing activity and gives the highest values in terms of petal number, ranks first due to the effect of phosphorus on flowering and flower quality. However, TV126C bacteria, which has strong nitrogen fix and weak phosphate solubilization activities, ranks second due to its bidirectional effect (Erman et al. 2024). With this research, it can be concluded that strong nitrogen activity has a positive effect on flower quality, even if the phosphorus effect is weak (Çığ et al. 2021).

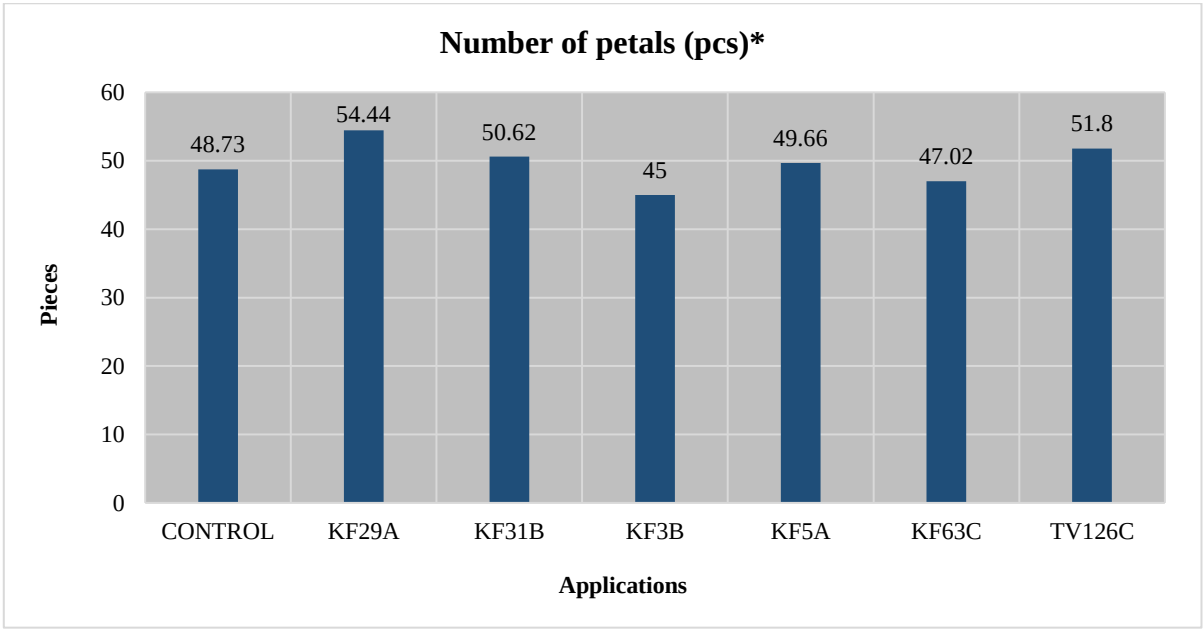

Figure 13- Number of petals (pieces) of carnation flowers, *: The differences between applications statistically are not significant

4.6. Flower diameter (mm)

The effects of bacterial applications on flower diameter length in carnation plants were found to be statistically significant (P<0.05). The highest flower diameter value was seen in the application of KF63C at 46.73 mm and KF5A at 46.32 mm and was statistically included in the same group. The lowest flower diameter value was found in the application of KF29A bacteria with 38.16 mm (Figure 14). The diameters of the control group carnation flowers were found to be higher than those of the carnations inoculated with KF29A, KF3B, and TV126C bacteria. It is seen that bacterial inoculations affect the diameter of carnation flowers at different levels. There is a difference of approximately 8 mm between the lowest and highest values between bacterial strains inoculations. Since flower size is also important in terms of flower quality, applications that have a positive effect on this parameter should be carefully evaluated.

KF63C, the bacterial application in which the highest value in terms of flower diameter is obtained, stands out with its versatile feature. It is thought that such bacteria cause improvements in flower quality because they contribute to resistance to nutrition and stress conditions with their nitrogen fixing, phosphate solubilization, siderophore production and ACC deaminase properties.

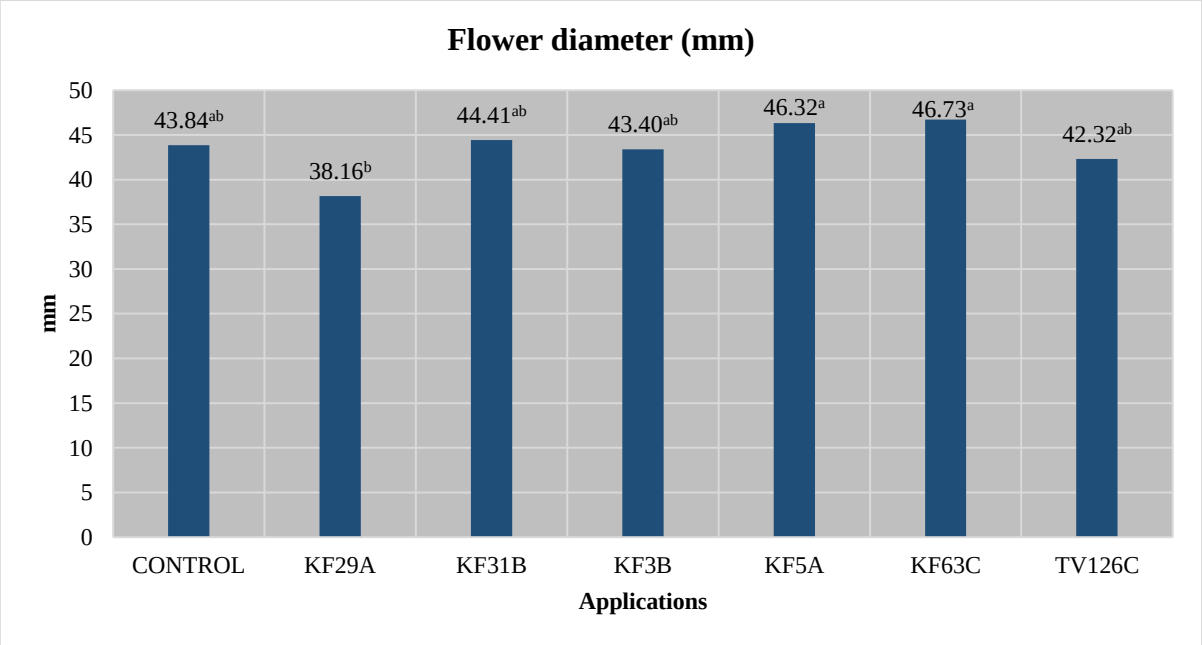

Figure14- Diameter of carnation flowers (mm), *: The differences between applications statistically are significant at P<0.05

4.7. Node number (pieces)

The effects of bacterial applications on the number of nodes in the carnation plant were found to be statistically insignificant. The number of nodes on the carnation branches of the control group was determined as 9.42. As a result of the applications in which bacterial inoculations were made, the number of nodes varied between 8.91 and 9.82, and the lowest and highest values were obtained in the inoculations of KF29A and TV126C bacterial strains, respectively. After TV126C and KF31B bacterial strains, the highest internode control group was determined in carnations (Figure 15).

TV126C, the bacterial application that gives the highest value in terms of number of branches, stands out with its strong nitrogen fixation and weak phosphate production. This dual feature reveals that nitrogen, in particular, encourages plant vegetative development, is effective in increasing the number of plant nodes and therefore in length, and is effective in flowering due to its phosphate solubilizing activity, although it is weak (Sonkurt & Çığ 2019). As a result of this research, selection of bacteria with dual activity and especially strong nitrogen fixation activity may contribute to cultivation for tall height and multiple flower setting.

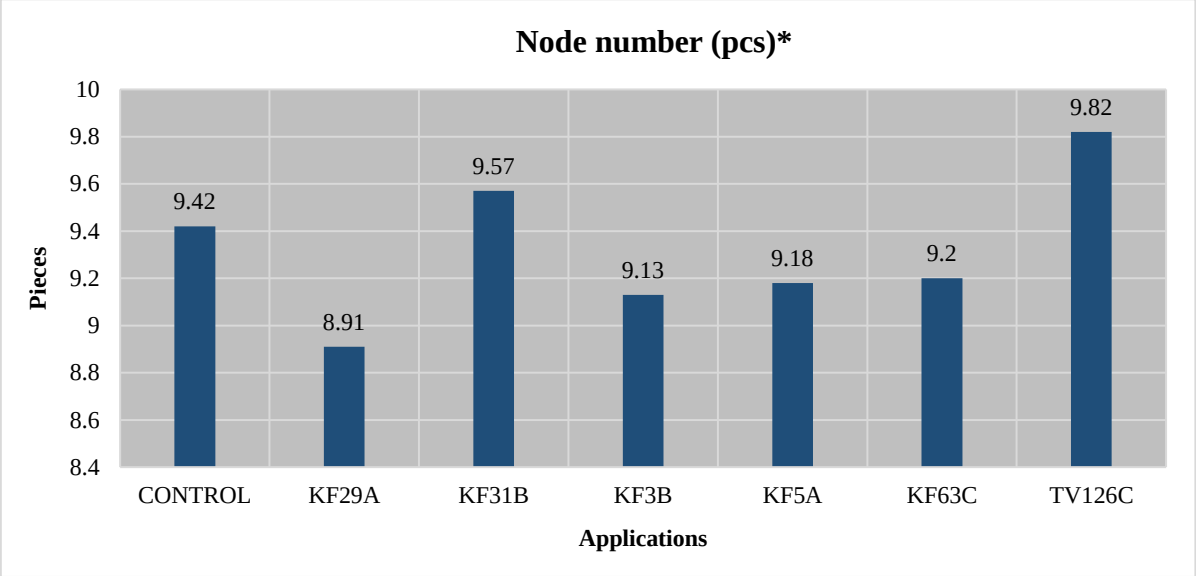

Figure 15- Node number of carnation plants (pieces), *: The differences between applications statistically are not significant

4.8. Internode length (cm)

The effects of bacterial applications on the number of nodes in the carnation plant were found to be statistically insignificant. The highest internode length was observed in the application of KF5A bacteria and 6.23 cm was obtained. The lowest internode length value was found to be 4.77 cm, and it was detected in the application of KF3B bacteria (Figure 16). The effect of the bacteria applied in our study on the internode length was not statistically significant. The internode length of the control group carnation plants was higher than the carnations in which KF3B and KF31B bacteria inoculations were made.

In the data obtained in the research, it is thought that the highest internode length was achieved with the application of KF5A bacteria, which has nitrogen-fixation and strong phosphate-solubilizing activity, and this result was achieved with the positive contribution of the dual synergistic effect. Similarly, it is thought that the partially superior effect of the KF5A bacterial species over other bacteria with dual properties may be due to its ability to combat other organisms in the soil and its greater effectiveness in plant-bacteria compatibility.

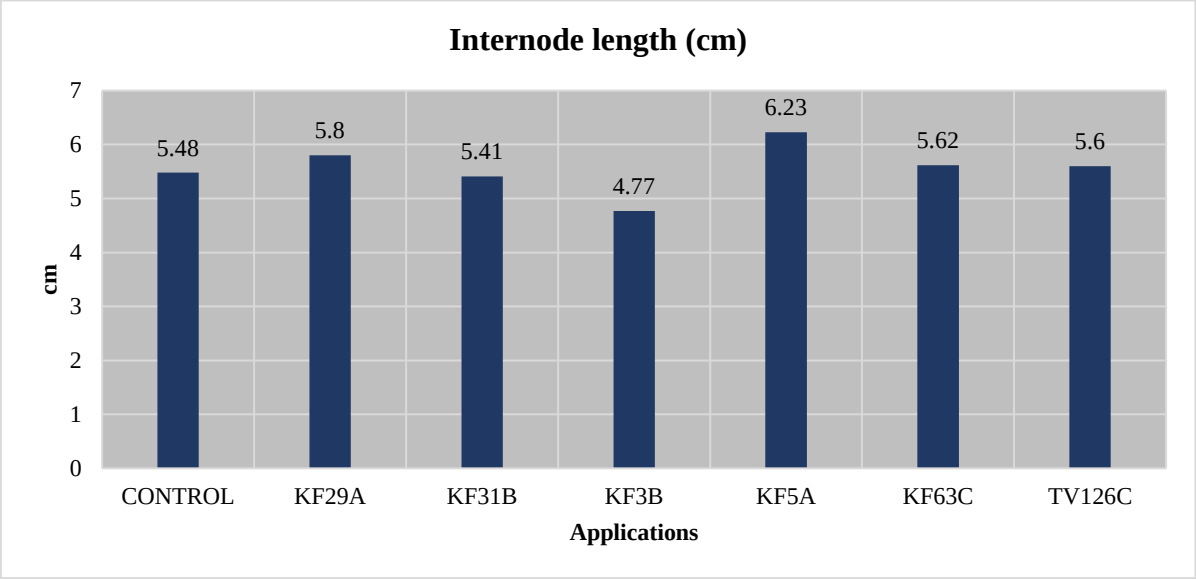

Figure 16- Internode length in carnation plant (cm), *: The differences between applications statistically are not significant

4.9. Flower stem thickness (mm)

The effects of bacterial applications on the flower stem thickness of the carnation plant were found to be statistically significant ($P<0.05$). The highest flower stalk thickness was determined as 3.39 mm and was determined in the application of KF3B bacteria. The lowest petiole thickness was 2.72 mm and was obtained with the application of KF63C bacteria (Figure 17).

It is thought that the main reason why KF3B bacteria show the highest value in terms of flower stalk thickness is due to its very strong ACC deaminase activity, unlike other bacteria. As it is known, ACC deaminase is effective by reducing the ethylene concentration in flowering, which is the generative period, and is known to extend this period (Söğüt & Çığ 2019). Thus, it is thought to have an effect on flower quality and therefore the thickness of the flower stem.

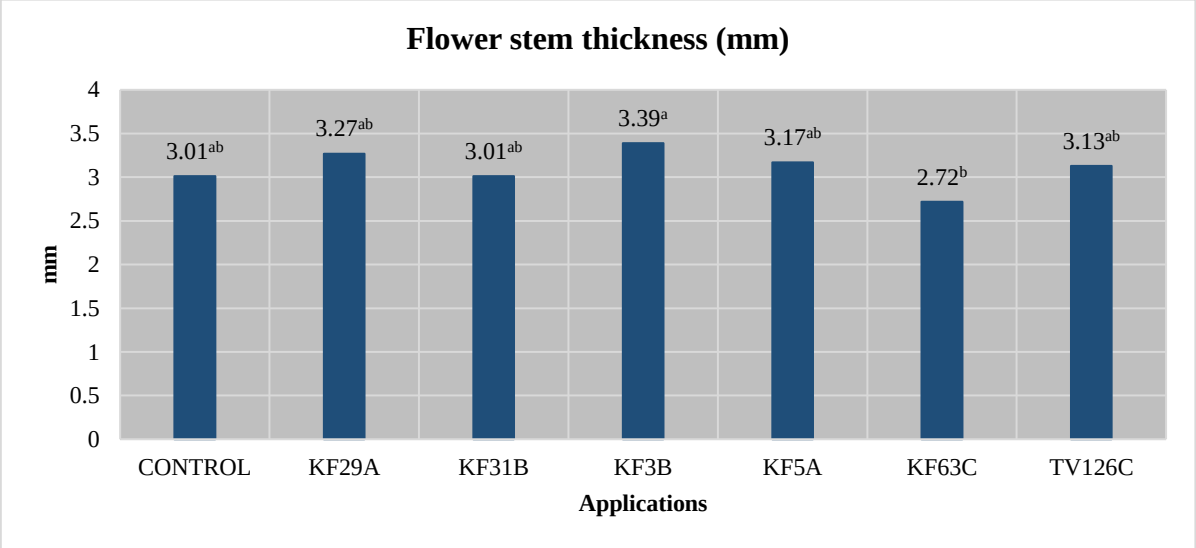

Figure 17- Flower stem thickness of the carnation plant (mm), *: The differences between applications statistically are significant at P<0.05

4.10. Flower stem length (cm)

The effects of bacterial applications on the flower stem length of the carnation plant were found to be statistically significant (P<0.01). The highest stem length (56.33 cm) was observed in TV126C bacteria inoculation, and the lowest stem length (44.97 cm) was determined in KF3B bacteria inoculation (Figure 18). Flower stem length is an important cut flower criterion for use in a vase. Although it is related to the various feature, it can be kept under control with applications or its length can be increased. In our study, the stem length of the control group carnations was found to be 50.86 cm, and it was recorded as higher than the stems of the carnations inoculated with KF3B, KF5A, and KF63C bacteria. These bacterial strains had a reducing effect of around 6 cm on the stem length of the control group plants. On the other hand, KF29A, KF31B, and TV126C bacterial inoculations increased stem length compared to control plants.

As a result of the study, it is thought that the main reason for obtaining the highest flower stem length with TV126C application is the high nitrogen amount resulting from its strong nitrogen fixation feature and therefore high vegetative development. In this way, an increase in height and therefore a higher flower stem length is achieved.

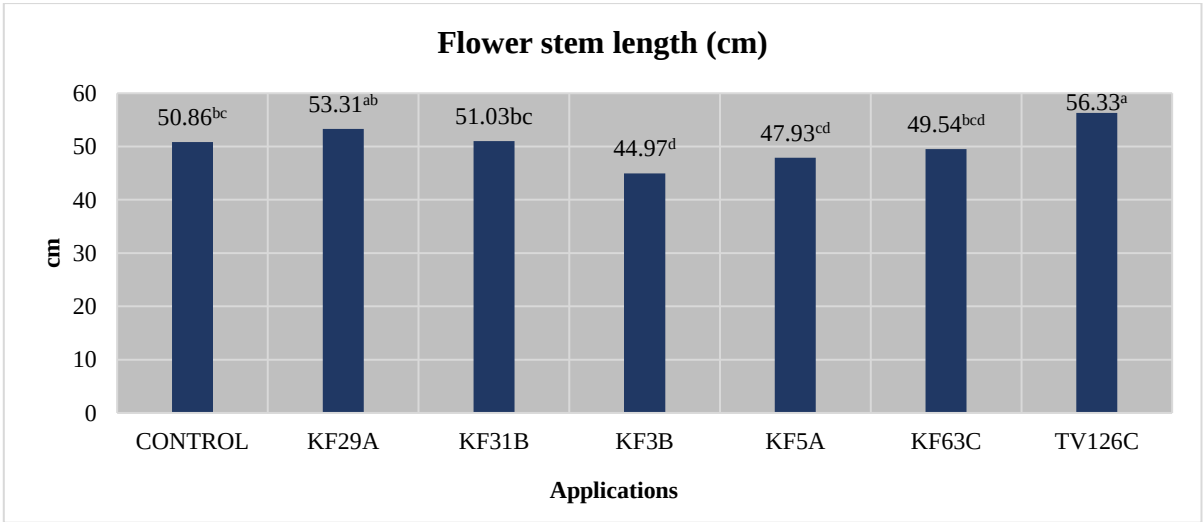

Figure 18- The length of the flower stalk of the carnation plant (cm), *: The differences between applications statistically are significant at P<0.01

4.11. Branch weight (g)

The effects of bacterial applications on the branch weight of the carnation plant were found to be statistically insignificant. The highest branch weight value (34.74 g) was observed with the application of KF63C bacteria, and the lowest branch weight value (29.51 g) was obtained with the application of KF5A bacteria (Figure 19). The average branch weight value of the control group carnations was found to be higher than the branch weight of the carnations inoculated with KF3B, KF31B, and KF5A bacteria. This creates the idea that some of these bacterial strains do not cause an increase in the branch weight and do not have a positive effect in this direction.

It is thought that the main reason why the highest value in terms of branch weight was obtained from the KF63C application is that it is a bacterial strain that is effective in terms of nitrogen fixation, ACC deaminase and siderophore production, as well as its strong phosphate solubilization activity. Likewise, it has been concluded that the main reason for obtaining higher values than other applications with similar features is high-level plant-bacteria interaction. Studies have shown that the exudates secreted by plants are used more effectively by some bacteria and affect some properties of the plant more (Glick 2020).

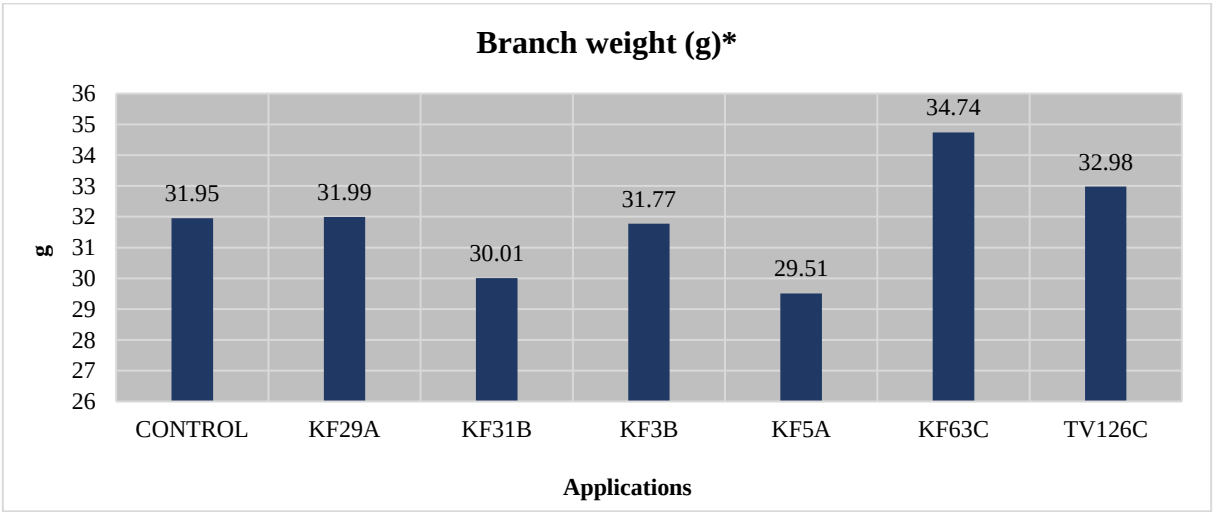

Figure 19- Branch weight of carnation plant (g), *: The differences between applications statistically are not significant

In the previous bacterial inoculation studies on ornamental plants, the results related to flowering were generally found to affect the beginning of flowering, harvest time, and plant growth parameters. In studies with tulips (*Tulipa gesneriana* L. cv. 'Clear Mater') in Faisalabad, *Burkholderia phytofirmans* (PsJN), T2 *Bacillus* sp. (MN-54), T3 *Enterobacter* isolates were used as foliar fertilizer. The results showed that the tulips responded well to bacterial treatments and significant improvements were observed in morphological traits and other quality criteria. During flowering, bacteria caused a delay of a maximum of 6 days and a minimum of 4 days compared to control treatments (Bashir et al. 2019). In the treatment of *Gladiolus grandiflorus* cv. White Friendship variety with *Rhizobium*, Phosphorous Solubilizing Bacteria (PSB), *Azotobacter* and *Azospirillum* biofertilizers, the control group plants emerged in the latest time. The highest values of plant height, the number of lamps per spike, branch length, and branch fresh weight were obtained in bacterial applications. Flower emergence time was determined early in control group plants (Ali et al. 2014). Bacterial applications caused late blooming. There is a partial similarity to these studies mentioned in our study. With the effect of bacteria, the beginning of flowering and harvesting time was detected earlier or later than the control, and this period even varied among bacteria.

In a field study in Egypt, three different biofertilizers were applied to the *Dahlia pinnata* var. Moonlight plant as single, double and triple applications. The highest flowering time was obtained with BİOgen (nitrogen fixation) + Phosphorein (phosphate solvent) + Active Dry Yeast (dry yeast) applications (Manoly & Nasr 2008). Increasing positive effects were determined in applications where bacteria were added.

In this study, the effects of biostimulants and biofertilizers on the growth, flowering, and quality of *Gladiolus grandiflorus* L. cv. American Beauty was determined under greenhouse conditions. Four biostimulants and three biofertilizers were applied. The results were obtained that the application of biostimulants and biofertilizers to the soil during planting and two months after planting will give higher vegetative growth, flowering, and quality parameters in gladiolus (Pansuriya et al. 2018).

In this study, the effect of organic fertilizers and biofertilizers on the growth and flowering of two standard carnations (*Dianthus caryophyllus* L.) Raggio-de-Sole and Murcia, when Raggio-de-Sole carnation variety is grown in sand + soil + vermicompost (1:1:1) When grown in (v/v) + inorganic fertilizers + biofertilizers @ 2 g/plant (*Azospirillum* and phosphate-solubilizing microorganisms), maximum plant height, the number of flowers, stem length, flower size, early flowering, the maximum percentage of class A flowers and vase life was obtained. (Bhalla et al. 2007). In our study, the effect of bacteria on

spray carnations is seen differently on these parameters. Some bacteria had an increasing effect on the investigated properties compared to the control group plants and some had a decreasing effect. It is thought that this may be due to the difference in bacterial breeds and carnation cultivars.

In the study conducted on the cultivation of six types of spray carnations in Bolu province, the plants came in 220 days from planting to harvest, and the flower stem length was 64.10-75.60 cm, the flower diameter was 42.08-51.25 mm, the flower stem thickness was 5.08-6.49 mm, the number of knots was 10.00-11.40 pieces, the branch weight was 45.73-73.67 g, and the number of buds varied between 2.70-5.00 pieces (Karadeniz et al. 2020). When the time from planting to harvest is evaluated, it can be said that the carnations inoculated with bacteria are exposed to much warmer conditions and the daylight because they are grown in Antalya, and it can be said that they are harvested in almost half the time of this study in Bolu. As it is understood from our study, other characteristics of the carnations in which bacteria were inoculated, except for the number of flower buds (bud), were below the range of values obtained by the researchers. Here, it was concluded that the number of buds in spray carnations is based on the cultivar trait, but other traits may be caused by the growing area and climate, and bacteria are not encouraging for these traits.

In our study, the bacterial strains inoculated to the root crown in the planting area of carnations were selected considering their specific characteristics, as shown in Table 3. The bacteria applied in many studies were generally selected from the same strains. In our study, it was tested in field and greenhouse conditions and its superiority was determined and was used by selecting from strains that are not frequently encountered in other studies.

Bacteria such as *Azospirillum, Acetobacter, Herbaspirillum, Azotobacter,* and *Azoarcus*, as root bacteria and plant growth-promoting bacteria, independent the nitrogen in the atmosphere that cannot be used by plants in the soil and turn it into a usable form (Enez 2022). The bacterial groups that solibilize phosphate best are the *Pseudomonas, Bacillus*, and *Rhizobium* families (Seshadri et al. 2000; Antoun 2002). Root bacteria synthesize ACC (1-amino-cyclopropone-1carboxylic acid) deaminase, keeping the ethylene level in the plant low, thus contributing to plant growth (Wang et al. 2000). According to Carrillo-Castañeda et al. (2005), chemical compounds produced by microorganisms around plant roots (in the rhizosphere) increase the presence and uptake of some essential minerals such as iron (Erdem 2013). Hydroxamate and catecholate siderophores produced by rhizospheric bacteria are used by plants. It has been reported that siderophores produced by *Pseudomonas* bind the necessary Fe-III, preventing spore formation of fungal pathogens and eliminating the disease (Montesinos et al. 2002). It has been reported that especially *Azotobacter* and *Pseudomonas* bacteria can be used in agricultural applications to increase product, quality, and yield, to make arid, industrially contaminated soils more suitable for agriculture due to salinity, and in biotechnological studies such as biological control against some plant pathogens (Cornelis & Matthijs 2007; Couillerot et al. 2009). Some bacterial species such as *Bacillus, Pseudomonas, Arthrobacter, Serratia*, and *Stenotrophomonas* stimulate plant growth by promoting volatile organic compounds (Seymen et al. 2019).

Bacteria families that contribute to the development and yield of cultivated plants can be expressed as *Artrobacter, Azoarcus, Azospirillum, Azotobacter, Bacillus, Burkholderia, Enterobacter, Klebsiella, Pseudomonas, Serratia* and *Rhizobia* (Burdman et al. 2000). Recent studies have shown that plant size and flower number and plant quality increase with different PGPR applications in ornamental plants grown in greenhouses and exposed to abiotic stress (Flores et al. 2007; Nordstedt et al. 2020). Positive effects on yield were observed when geranium (*Pelargonium graveolens* L. Herit) plant was inoculated with *Bacillus subtilis* (MA-2) and *Pseudomonas fluorescens* (MA-4) bacteria (Mishra et al. 2010). Plant growth, nitrogen content, and root colonization were increased when *Amaranthus paniculatus* and *Eleusine coracana* plants were inoculated with *Pseudomonas corrugata, P. corrugata* 1, *P. corrugata* 7, and *Azotobacter chroococcum* (Pandey et al. 1999). The highest rooting rate was achieved with the use of *Bacillus megaterium* and *Pseudomonas fluorescens* bacteria in *Rosa canina* cuttings (Kınık 2014). *Bacillus subtilis* bacteria increased root formation and *Pseudomonas putida* bacteria increased the number of leaves in *Ficus benjamina* L. (Sezen et al. 2014). In a study investigating the effects of three different *P. putida* strains and their mixtures on two poinsettia (*Euphorbia pulcherrima*) cultivars, an increase in plant growth and anthocyanin pigmentation was found. The effect of *P. putida* on cyathia number, root volume, number of leaves, and leaf area was significantly affected compared to the control. In addition, *P. putida* played an important role in the coloration of the bracts (Zulueta-Rodriguez et al. 2014). *Rosa damascena* Mill. F6 (*Pseudomonas fluorescens*), LSI19 (*Rhizobium leguminosarum*), and LC4 (*Vibrios vulnificus*) bacterial isolates were effective on shoot and root development, root growth, root length, and root fresh and dry weight parameters in cuttings of the plant (Tariq et al. 2016).

As can be seen from Table 1, KF29A: *Enterobacter ludwigii*, KF31B, *Pseudomanas fluorescens*; KF3B: *Paenarthrobacter nitroguaiacolicus*, KF5A: *Pseudomonas* sp. Strain VG242B and KF63C: *Paenibacillus xylanilyticus* bacteria are all sufficient in terms of nitrogen fixation, while TV126C: *Pseudoalteromonas tetraodonis* bacteria is stronger than the others. Phosphate solubilizing properties of bacteria strains KF3B: *Paenarthrobacter nitroguajacolicus* and TV126C: *Pseudoalteromonas tetraodonis* are absent or weak, respectively. Phosphate solubilizing abilities of other bacterial strains are better (++) than these two strains. Bacteria with ACC deaminase synthesizing power were evaluated as KF3B *Paenarthrobacter nitroguajacolicus* (very good/+++), KF63C: *Paenibacillus xylanilyticus* (moderately good/++), and TV126C *Pseudoalteromonas tetraodonis* (good/+). Except for TV126C: *Pseudoalteromonas tetraodonis* bacteria, which do not perform in the production of siderophores, the performance of KF5A group bacteria strains is good in this feature.

KF63C: *Paenibacillus xylanilyticus* bacterial strain was the bacterial strain that shortened the bud opening, full flowering, and harvest time, and increased the flower diameter and branch weight the most compared to other applications. Since this bacterial strain is strong in terms of nitrogen fixation, phosphate solubilizing, ACC deaminase synthesis, and siderophore production, it provided earliness in our carnation variety. On the other hand, KF5A: *Pseudomonas* sp. strain VG242B, on the other hand, was the most effective bacterial strain in internode length, as it can fix nitrogen, solubilize phosphate and produce siderophores. It was determined that the plants inoculated with KF31B: *Pseudomonas fluorescens* performed better than the plants treated with some control group bacteria based on the parameters examined, considering that this bacterial strain has good nitrogen fixing, phosphate solubilizing, and sidereophore production properties. The best development was recorded in the number of flower buds and nodes and the length of the flower stalk in carnations infected with TV126C: *Pseudoalteromonas tetraodonis* bacteria strain.

5. Conclusions

While some bacteria have positive effects on some parameters, some bacteria have lower effects both among themselves and compared to the control group plants. Generally, bacteria have had positive effects on the carnation plant.

Bacterial inoculation at each stage of flowering appears to cause a delay of about 10-30 days. Of these, only one bacterial strain (KF63C) provided earliness. Bacterial applications that cause late flowering according to the emergence times of some diseases and pests may be advantageous. In addition, 10-30 days of late flowering can give us an advantage that we are continuing while the product is finished in the market.

New alternatives are sought to minimize the high cost and destructive effect of inorganic fertilizers. To fill this gap, there is a growing demand for the use of organic fertilizers that have the least impact on nature. In light of this increasing demand and commercial input, researches are continuing to reduce costs in many plants. In this study, beneficial bacteria were shown to improve the development and flower quality of the carnation plant.

As seen in previous studies, bacterial application with chemical fertilizers can increase plant growth and flowering. Considering the pollution and high cost of chemical fertilizers that are used too much, it is necessary to increase the use of bacteria and to carry out more studies in this area. Biological fertilization should be adopted as an alternative way of fertilization for carnation plants.

As it is understood from this study, although the carnation plants affected by the inoculated bacteria showed better growth compared to the control group plants and conformed to the cut flower criteria, it should not be forgotten that PGPR will have a positive effect if the appropriate environment and plants are selected, as Çığ et al. (2017) stated.

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References

Ahemad M & Khan M S (2012). Productivity of greengram in tebuconazole– stressed soil, by using a tolerant and plant growth-promoting *Bradyrhizobium* sp. MRM6 strain. Acta Physiol. Plant 34: 245-254 https://doi.org/10.1007/s11738-011-0823-8

AIPH U F (2019). International Statistics Flowers and Plants Yearbook. AIPH University, Urban

Ali A, Mehmood T, Hussain R, Bashir A S, Raza S & Najam-ud-Din Ahmad (2014). Investigation of biofertilizers influence on vegetative growth, flower quality, bulb yield and nutrient uptake in Gladiolus (*Gladiolus grandiflorus* L.) *International Journal of Plant, Animal and Environmental Sciences* 4(1): 94-99

Ali S, Charles T C & Glick B R (2012). Delay of flower senescence by bacterial endophytes expressing 1-aminocyclopropane-1-carboxylate deaminase. J. Appl. Microbiol 113: 1139-1144 https://doi.org/10.1111/j.1365-2672.2012.05409.x

Alkaç O S, Güneş M & Belgüzar S (2023). Effects of organic acids, chemical treatments and herbal essential oils on the vase life of cut carnation (*Dianthus caryophyllus* L.) flowers. *Emir. J. Food Agric* 35(4): 332-341 https://doi:10.9755/ejfa.2023.v35.i4.3002

Antoun H (2002). Field and greenhouse trials performed with phosphate solubilizing bacteria and fungi. In: First International Meeting on Microbial Phosphate Solubilization, 16-19 July, Salamanca Spain, pp. 29-31

Asri Öktüren F, Demirtaş Işıl E, Güven D, Özkan C & Arı A (2016). Determination of some fertility status of carnation greenhouse soils in Kepez district of Antalya. *Journal of Agriculture Faculty of Ege University* 53(4): 383 - 388 (in Turkish)

Atakan A & Özgönen Özkaya H (2018). The determination of the prevalence of soil-borne fungal disease of carnation greenhouses in Antalya province. *Süleyman Demirel University Journal of Natural and Applied Sciences* 22(1): 216 - 220 (in Turkish) https://doi:10.19113/sdufbed.04574

Bashir M, Asif M, Naveed M, Qadri R WK, Faried N & Baksh A (2019). Pre-harvest exogenous application of bacterial strains to assess the flower and bulb quality of cut Tulip (*Tulipa gesneriana* L.) cv. Clear Water. Discovery 55(278): 3-80

Besemer S T (1980). Carnations. (In: Introduction to Floriculture, Editor: Roy A. Larson) Academic Press. Inc. New York

Bhalla R B, Kumar M S & Jain R K (2007). Effect of organic manures and biofertilizers on growth and flowering in standard carnation (*Dianthus carypohyllus* Linn.). *Journal of Ornamental Horticulture* 10(4)*:* 229-234

Burdman S, Jurkevitch E & Okon Y (2000). Recent advances the use of plant growth promoting rhizobacteria (PGPR) in agriculture. In: N S Subba Rao & Y R Dommergues (Eds.), Microbiol Interactions in Agriculture and Forestry Vol II, 10, Science Publishers, Inc. UK, pp. 229-250

Carrillo-Castañeda G, Muñoz JJ & Peralta-Videa JR (2005). A spectrophotometric method to determine the siderophore production by strains of fluorescent *Pseudomonas* in the presence of copper and iron. *Microchemical Journal* 81(1): 35-40 https://doi.org/10.1016/j.microc.2005.01.018

Cornelis P & Matthijs S (2007). *Pseudomonas* siderophores and their biological significance. Chapter: 9, In: A.Varma & S B Chincholkar (Eds.), Microbial Siderophores, Soil Biology, vol 12. Springer, Berlin, Heidelberg. pp. 193-203 https://doi.org/10.1007/978-3-540-71160-5

Couillerot O, Prigent-Combaret C, Caballero-Mellado J & Moënne-Loccoz Y (2009). *Pseudomonas fluorescens* and closely-related fluorescent pseudomonads as biocontrol agents of soil-borne phytopathogens. Lett Appl Microbiol 48(5): 505-512 https://doi.org/10.1111/j.1472-765X.2009.02566.x.

Çakmakcı R (2009). Promotion of plant growth by ACC deaminase-producing plant growth promoting bacteria under stress conditions. *Atatürk Univ., J. of the Agricultural Faculty* (current name: Research in Agricultural Sciences) 40(1): 109-125 (in Turkish)

Çakmakçı R (2005). Phosphate solubilizing bacteria and their role in plant growth promotion. *Selcuk Journal of Agriculture and Food Sciences* (formerly name: Journal of Selcuk University Agricultural Faculty) 19(35): 93-108 (in Turkish)

Çelik Y, Yarşi G & Özarslandan A (2020). Effects of beneficial bacteria applications on plant yield and resistance mechanisms. JOGHENS Journal of Global Health & Natural Science 3(1): 37-44 (in Turkish)

Çığ F, Sönmez F, Nadeem, MA & Sabagh AE (2021). Effect of biochar and PGPR on the growth and nutrients content of einkorn wheat (*Triticum monococcum* L.) and post-harvest soil properties. Agronomy 11: 2418 https:// doi.org/10.3390/agronomy11122418

Çığ F, Sonkurt M, Erman M & Çığ A (2017). The role of beneficial microorganisms in the protection of plants growing in natural landscape areas. Chapter: 35, In: Nature, Environment and Earth Science Current Trends in Science and Landscape Management. Sofia St. Kliment Ohridski University Press Sofia, Bulgaria, ISBN 978-954-07-4338-7. pp. 427-442

Dejordjevic M A, Gabriel DW & Rolfe B G (1987). Rhizobium-the refined parasite of legumes. Annu. Rev Phytopathology 25: 145-168 https://doi.org/10.1146/annurev.py.25.090187.001045

Düzgünes O, Kesici T, Kavuncu O & Gürbüz F (1987). Research and Experiment Methods (Statistics Methods-II), Publication No: 1021, Textbook: 295, A.Ü. Faculty of Agriculture Publications, Ankara, 381p (in Turkish)

Enez B (2022). The effect of bacteria on plant growth. Chapter 1. In: M Kırıcı & E Karakaya (Eds.), From Theory to Practice Agriculture and Livestock Practices in Turkey, Iksad Publications ISBN: 978625-8246-964. Ankara, pp. 3-16 (in Turkish)

Erdem B (2013). Microbial siderophores and their biotechnologyical applications. The Black Sea Journal of Sciences 3(8): 77-88 (in Turkish)

Erman M, Kotan R, Çakmakci R, Çiğ F, Karagöz K, Sönmez F & El-Sabagh A (2024). Diversity and metabolic potential of culturable N2-fixing and P-solubilizing bacteria from rhizosphere of wild crops in Van Lake basin-Turkey. Pak. J. Bot., 56(2): http://dx.doi.org/10.30848/PJB2024-2(11)

Erman M, Kotan R, Çakmakçı R, Çığ F, Karagöz K & Sezen M (2010). Effects of the nitrogen fixing and phosphate solubilizing bacteria isolated from Van Lake Basin on growth and yield characteristics in sugar beet. In: Türkiye IV. Organic Agriculture Symposium, 28 June - 1 July 2010, Erzurum, 326 pp

Ferreira M C B, Fernandes M S & Döberenier J (1987). Role of *Azospirillum brasilense* nitrate reductase in nitrate assimilation by wheat plants. Biol and Fert of Soils 4: 47-53 https://doi.org/10.1007/BF00280350

Flores A C, Luna A A E & Portugal V O (2007). Yield and quality enhancement of marigold flowers by ınoculation with *Bacillus subtilis* and *Glomus fasciculatum.* Journal of Sustainable Agriculture 31(1): 21-31 https://doi.org/10.1300/J064v31n01_04

Glick B R (2020). Introduction to Plant Growth-Promoting Bacteria. In: Beneficial Plant-Bacterial Interactions. Springer, Cham. https://doi.org/10.1007/978-3-030-44368-9_1

Google Earth (2023). https://earth.google.com/web/search/36.973333333+,+30.81361 1111/@36.9733337,30.81361323,81.0933258a,823.46533885d,35y,-103.24204733h, 44.9 9999825t,0r/data=Cl8aNRIvGcvNgS-WfEJAIZ8pKtFI0D5AKhszNi45NzMzMzMzMzMzMgLCAzMC44MTM2MTExMTEYASABIiYKJAnYQouByXxCQBFLHMO97ntCQBnY WJb5BNI-QCFoO5 ujgM8-QA (Aces date: 13.03.2023)

Gunjal A B & Glick B R (2023). Plant growth-promoting bacteria (PGPB) in horticulture. Proceedings of the Indian National Science Academy (2023) https://doi.org/10.1007/s43538-023-00224-3

Gül A, Kıdoğlu F, Tüzel Y & Tüzel İ H (2008). Effects of nutrition and *Bacillus amyloliquefaciens* on tomato (*Solanum lycopersicum* L.) growing in perlite. *Spanish Journal of Agricultural Research* 6(3): 422-429 https://doi.org/10.5424/sjar/2008063-335

Güneş M & Babadağ G E (2022). Current status of businesses, problems and solutions of retail ornamental plants of Konya. *Gaziosmanpasa Journal of Scientific Research* 11(3): 137-146 (in Turkish)

Karadeniz T, Güler E, Koçoğlu S T, Kuru Berk S & Bak T (2020). Carnation (*Dianthus caryophyllus*) growing in greenhouse conditions in Bolu. *IJAAES International Journal of Anatolia Agricultural Engineering* 2: 11-15 (in Turkish)

Keçecioğlu O (2001). Studies on importance of western flower thrips *Frankliniella occidentalis* (Pergande) (Thysanoptera: Thripidae) and development of chemical control on carnation in greenhouse conditions in Antalya. Unpublished Msc Thesis, Ege University, Graduate School of Natural and Applied Sciences, İzmir, 54 pp (in Turkish)

Keçecioğlu O & Madanlar N (2002). The effects of some insecticides on western flower thrips *Frankliniella occidentalis* (Pergande) (Thysanoptera: Thripidae) on carnation in greenhouses. *Turkish Journal of Entomology* 26(2): 147 - 154 (in Turkish)

Kınık E (2014). Effects of auxin, mycorrhiza and plant growth promoting bacteria treatments on propagation of some woody ornamental plants by cutting. Unpublished Msc Thesis, Ondokuz Mayıs University Graduate School of Natural and Applied Sciences, Samsun, 107 p. (in Turkish)

Kloepper J W, Leong J, Teintze M & Scrotch M N (1980). Enhanced plant growth by siderophores produced by plant growth-promoting rhizobacteria. Nature 286: 885-886 https://doi.org/10.1038/286885a0

Kumar T S (2021). Evaluation of potential biocontrol agents on root knot nematode meloidogyne incognita management in carnation (*Dianthus caryophyllus* L.). *International Journal of Current Microbiology and Applied Sciences* 10(02): 1786-1790 https://doi.org/10.20546/ijcmas.2021.1002.211

Manoly N D & Nasr A A (2008). Response of *Dahlia pinnata* plants to biofertilizer types. Egyptian Journal of Experimental Biology 4: 87-91

Mayak S, Tirosh T & Glick BR (2004). Plant growth-promoting bacteria confer resistance in tomato plants to salt stress. Plant Physiol. Biochem. 42 (6): 565-572 http://doi.org/ 10.1016/j.plaphy.2004.05.009

McCain A H (2003). Disease of Carnation (*Dianthus caryophylius* L.). https://www.apsnet.org/edcenter/resources/commonnames/Pages/Carnation.aspx (Access date: 22.02.2024)

Meena P & Rai A K (2017). Effect of PGPR on morphological properties of different varieties of wheat (*Triticum aestivum*). The Pharma Innovation Journal 6(7): 271–277

Mishra R K, Prakash O, Alam M & Dikshit A (2010). Influence of plant growth promoting rhizobacteria (PGPR) on the productivity of *Pelargonium graveolens* L. Herit. Recent Res Sci Technol 2(5): 53-57

Montesinos E, Bonaterra A, Badosa E, Francãç J, Alemany J, Llorente I & Moragrega C (2002). Plant-microbe interactions and the new biotechnological methods of plant disease control. Int Microbiol 5 (4): 169-175 https://doi.org/10.1007/s10123-002-0085-9.

Nordstedt N P, Chapin L J, Taylor C G & Jones M L (2020). Identification of *Pseudomonas* spp. that increase ornamental crop quality during abiotic stress. Frontiers in Plant Science 10: 1754 https://doi.org/10.3389/fpls.2019.01754

Pandey A, Durgapal A, Joshi M & Palni L M S (1999). Influence of *Pseudomonas corrugata* inoculation on root colonization and growth promotion of two important hill crops. Microbiol Res 15(3): 259-266 https://doi.org/10.1016/S0944-5013(99)80023-8

Pansuriya P B, Varu D K & Viradia R R (2018). Effect of biostimulants and biofertilizers on growth, flowering and quality of gladiolus (*Gladiolus grandiflorus* L.) cv. American Beauty under greenhouse conditions. *International Journal of Chemical Studies* 6 (2): 2191-2196

Ram R L, Maji C & Bindroo B B (2013). Role of PGPR in different crops-an overview. Indian Journal of Sericulture 52(1): 1-13

Seshadri S, Muthukumarasamy R, Lakshminarasimhan C & Lgnacimuthu S (2000). Solubilization of inorganic phosphates by *Azospirillum halopraeferans*. Current Science 79(5): 565-567

Seymen M, Kurtar E S, Dursun & Türkmen Ö (2019). In Sustainable agriculture: assessment of plant growth promoting rhizobacteria in cucurbitaceous vegetable crops. In: DK Maheshwari & S Dheeman (Eds.), Springer Nature Switzerland AG 2019 Field Crops: Sustainable Management by PGPR, Sustainable Development and Biodiversity 23, pp. 69-103. https://doi.org/10.1007/978-3-030-30926-8_4

Sezen I & Külekçi A E (2020). Effects of plant growth promoting bacteria on the growth parameters of ornamental plants. *Journal of Agricultural Faculty of Bursa Uludag University* 34 (special issue): 9-20 (in Turkish)

Sezen I, Kaymak H Ç, Aytatlı B, Dönmez M F & Ercişli S (2014). Inoculations with plant growth promoting rhizobacteria (PGPR) stimulate adventitious root formation on semi-hardwood stem cuttings of *Ficus benjamina* L. Propagation of Ornamental Plants 14(4): 152-157

Sonkurt M & Çığ F (2019). The effect of plant growth-promoting bacteria on the development, yield and yield components of bread (*Triticum aestivum* L.) and durum (*Triticum durum*) wheats. Applied Ecology and Environmental Research 17(2): 3877-3896 http://dx.doi.org/10.15666/aeer/1702_38773896

Söğüt S & Çığ F (2019). Determination of the effect of plant growth promoting bacteria on wheat (*Triticum aestivum* L.) development under salinity stress conditions. Applied Ecology and Environmental Research 17(1): 1129-1141 http://dx.doi.org/10.15666/aeer/1701_11291141

Şevik M A & Saruhan İ (2010). Plant protection problems in carnation (*Dianthus caryophyllus* L.). Turkish Journal of Scientific Reviews 3(2): 33-41 (in Turkish)

Tariq U, Riaz A, Jaskani M J & Zahir Z A (2016). Screening of PGPR isolates for plant growth promotion of *Rosa damascena* Mill. International Journal of Agriculture and Biology 18(5): 997-1003 https://doi.org/10.17957/IJAB/15.0200

Tozlu E, Karagöz K, Babagil G E, Dizikısa T & Kotan R (2012). Effect of some plant growth promoting bacteria on yield, yield components of dry bean (*Phaseolus vulgaris* L. cv. Aras 98). Atatürk Univ., *J. of the Agricultural Faculty* 43: 101–106

TUİK (2019). Bitkisel üretim İstatistikleri. Türkiye İstatistik Kurumu. (https://www.tuik.gov.tr/Bulten) https://data.tuik.gov.tr/Bulten/Index?p=Bitkisel-Uretim-Istatistikleri-2021-37249 (Access date: 15.10.2022)

TUİK (2020). Bitkisel üretim İstatistikleri. Türkiye İstatistik Kurumu. (https://www.tuik.gov.tr/Bulten) https://data.tuik.gov.tr/Bulten/Index?p=Bitkisel-Uretim-Istatistikleri-2021-37249 (Access date: 15.10.2022)

TUİK (2021). Bitkisel üretim İstatistikleri. Türkiye İstatistik Kurumu. (https://www.tuik.gov.tr) https://data.tuik.gov.tr/Bulten/Index?p=Bitkisel-Uretim-Istatistikleri-2021-37249 (Access date: 14.01.2023)

TUİK (2022). Bitkisel üretim İstatistikleri. Türkiye İstatistik Kurumu. (https://www.tuik.gov.tr) https://data.tuik.gov.tr/Bulten/Index?p=Bitkisel-Uretim-Istatistikleri-2021-37249. (Access date: 20.03.2023)

TUİK (2023). Türkiye Süs Bitkileri Üretim Verileri. Türkiye İstatistik Kurumu. https://data.tuik.gov.tr/Kategori/GetKategori?p=tarim-111&dil=1 (Acces date: 16.02.2023)

Tunç İ & Göçmen H (1995). Notes on two greenhouse pests, *Polyphagotarsonemus latus* (Banks) (Acrina, Tarsonemidae) and *Frankliniella occidentalis* (Pergande) (Thysanoptera, Thripidae), found in Antalya *Turkish Journal of Entomology* 19(2): 101-109

Wang C, Knill E, Glicl B R & Defago G (2000). An ACC deaminese gene improves the growth promoting and diseasefluor suppressive capacities of *Pseudomonas escens* strain CHAO. In: Fifth International PGPR Workshop, 29 October November, 2000, CordobaArgentina.3

Wani P A & Khan M S (2010). *Bacillus* species enhance growth parameters of chickpea (*Cicer arietimum* L.) in chromium stressed soils. Food Chem. Toxicol 48: 3262-3267. https://doi.org/10.1016/j.fct.2010.08.035

Whealy A & Larson R A (1992). Carnations. Introduction to Floriculture. Academic Press, New York, 292 pp

Zaman S, Özdemir Ü & Sever R (2011). Production of decorative plants and geographical conditions in Antalya. Eastern Geographical Review 12(18): 301-326 (in Turkish)

Zulueta-Rodriguez R, Cordoba-Matson M V, Hernandez-Montiel L G, MurilloAmador B, Rueda-Puente E & Lara L (2014). Effect of *Pseudomonas putida* on growth and anthocyanin pigment in two poinsettia (*Euphorbia pulcherrima*) cultivars. *The 19 Scientific World Journal*, Volume 2014, Article ID 810192, 6 pages. https://doi.org/10.1155/2014/810192

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Machine Learning-Based Grasshopper Species Classification using Neutrosophic Completed Local Binary Pattern

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ABSTRACT
Locusts are seen as a major threat to the ecosystem because they devastate crops and contribute to thousands of tons food lost every year. Numerous well-trained agents are needed for the efficient control of these insects. However, this is a challenging process. Grasshopper detection methods are being developed using traditional forecasting methods by expert entomologists. The maximum potential of these methods has not yet been completely realized. Hence the majority of work is still done manually. In this paper, a neutrosophic CLBP (completed local binary pattern) based grasshopper species classification framework is proposed. Our proposed system comprises a novel grasshopper species database of over 7.392 images for grasshopper species classification. The grasshopper image is first converted to a neutrosophic field. These discriminatory features are merged with rotation invariant LBP. Our proposed system could achieve up to 99.7% classification accuracy even while working with challenging datasets of wide image quality and size range. The proposed methodology involved diagnosing 11 species and subspecies. It demonstrates the impracticability of conventional diagnostic techniques in the later stages. It could have a big impact on data analysis, enabling more effective handling of global pest.

Keywords: Neutrosophic set, Local binary pattern, Locust, Deep learning, Machine learning

1. Introduction

Insects are important in the ecological and economic life of humans and other living things. For example, they may cause direct product losses by feeding on agricultural and forest products (Gullan & Cranston 2014). Locust infestations have deleterious consequences on the food accessibility and socio-economic fabric of rural communities. The financial outlay for the eradication of these insects may extend into the millions and requires a certain amount of expert training. Additionally, the extensive use of chemical insecticides might have detrimental environmental repercussions (Zhang et al. 2019). Therefore, precise automated locust detection systems hold the potential to attenuate the reliance on a multitude of pesticides in the context of locust management. Grasshoppers are a pest that is wreaking havoc all over the planet. They could starve millions of people to death and destroy crops worth billions of dollars every year. Depending on factors like temperature and vegetation, they could rapidly multiply twenty times (FAO 2020). However, the amount of data to be estimated by traditional approaches is limited and unreliable. To combat locusts effectively, experts are moving away from a reliance on heavy insecticide use and instead integrating quantitative metrics with on-site observations from specialists. This data fusion approach is crucial for the development of precise, automated locust control systems that can target specific types, developmental stages, and crop vulnerabilities.

A paucity exists in the realm of non-invasive and cost-effective methodologies for the detection and classification of insect diversity, rendering the current state devoid of an efficacious approach. Conventional methodologies form the basis of comparative morphological and insect taxonomy studies. In taxonomy, molecular and molecular cytogenetic research techniques have recently become very prominent (Sreedevi et al. 2015). Classical taxonomy offers the most practical and accurate classification based on general commonalities and the most obvious characteristics of species. It is crucial for managing biological collections and identifying species (using identification keys). Initial endeavors in classification were constrained to taxonomic attributes of the organism, neglecting considerations of interspecies relatedness. The phylogenetic classification emerged later in the 1950s to handle the evolutionary background of the creature. Here are the various schools of conventional taxonomy that, although adhering to the same principle of morphological similarity between species, diverge in how they see phylogenetic classification (Sinev 2012). There are also many different sampling and monitoring methods. Direct observations,

direct sampling, and DNA-based methods are some of these methods. The pitfall traps are one of the most criticized but frequently used methods (Engel et al. 2017). They are invasive because they wipe study instances out of the environment. Moreover, the explication of variations across habitats poses challenges, given that each trapping technique is imbued with distinct biases and methodological idiosyncrasies (Skvarla et al. 2014). The direct observation method is non-invasive. Nonetheless, it necessitates the discernment of organisms by proficient entomologists within the study locale during the designated sampling period. This predicament significantly diminishes the potential pool of instances under consideration. (Hansen et al. 2020).

The enormous species diversity of insects (more than 1.02 million species reported so far) makes identification difficult (Zhang 2011). Besides, the substantial variety within species is caused by factors like sex, color morph, life stage, etc. Higher taxonomic categories, such as orders, could be distinguished with practice. However, once we get down to the family level, even for specialists, the work becomes rather difficult unless we narrow the problem down to a certain life stage, location, or insect order. The challenge of identification grows harder the lower the taxonomic level. Reliable species identification may necessitate years of education and specialization in a single insect taxon. These highly qualified taxonomists generally have insufficient time, especially for less conspicuous and aesthetically pleasing groupings. They need to use their time better elsewhere rather than on routine identifications (Chudzik et al. 2020). It is critical to identify insects according to species or higher taxonomic categories quickly and accurately in many situations. A significant fraction of the biological diversity in our world is made up of insects, and advancement in our understanding of the make-up and operation of the earth's ecosystems depends partly on our capacity to locate and recognize the insects that live there successfully. Concerns about the safety of human food and health also call for the quick and precise identification of insects (Valan et al. 2019).

In many sectors, machine learning and image processing have immense potential. Self-driving automobiles, improvements in medical technologies, and transportation are just a few examples of beneficial applications for this technology. There are still a lot of applications for it, though, and it has not yet reached its full potential. The image processing-based methods provide significant advantages over conventional entomology approaches. They also sample more individuals without destroying habitats or depleting the population of the species. Moreover, they need less maintenance (Collett & Fisher 2017). These systems were employed to detect and classify insects and other arthropods infrequently but progressively (Martineau et al. 2017; Hansen et al. 2020). However, it is difficult to distinguish insects in nature due to diversity and their responses to the environment. These issues pose a significant challenge for computer vision systems. The computer vision-based grasshopper and locust detection systems are still in their infancy. It is a manual process carried out by specialist agents or farmers. Liu et al. proposed a computer vision-based pest detection and classification system (Liu et al. 2016). They used saliency map and deep CNN learning methods. They obtained a dataset from the internet. They have carried out their experiments on a high-performance computer. Liu et al. proposed a novel pest detection network in laboratory conditions (Liu et al. 2019). The proposed network gives 75% mean accuracy and precision. Xia et al. proposed a fast region-based convolutional neural network (Fast RCNN) based insect detection system (Xia et al. 2018). They have obtained 89% detection accuracy. They have also obtained datasets from the internet. Ding & Taylor proposed a moth detection approach (Ding & Taylor 2016). A sliding window technique was employed, covering the entire image in their approach. In their strategy, anchor boxes were utilized to handle the entire image in a single iteration.

Species identification is very popular for mammals and birds (Norouzzadeh et al. 2018). However, arthropod-focused computer vision experiments have concluded that it is almost impossible for humans to identify species solely on images (Hansen et al. 2020). There is a need for automatic species detection and classification systems to take full advantage of image processing-based systems (Hansen et al. 2020). The species-level arthropod classification is carried out from museum collections (Hansen et al. 2020). They used a convolutional neural network (CNN) for classifying arthropods. Kasinathan et al. proposed an insect pest detection method (Kasinathan et al. 2021). The Wang, Xie, Deng, and IP102 datasets have been used. They have obtained 91.5% classification accuracy for nine class with the CNN model. Cheng et al. proposed a pest identification algorithm (Cheng et al. 2017). They used deep residual learning. They have obtained 98.67% classification accuracy for 10 classes. Xia et al. used an improved CNN model for the classification of crop insects. They have used an improved CNN model. Xie et al. used multi-level unsupervised feature learning methods (Xie et al. 2018) for pest identification. Nanni et al. proposed different Adam optimization methods for pest identification (Nanni et al. 2022). They have obtained 95.52% and 74.11% classification accuracy on Deng and IP102 datasets respectively.

It is important to extract textural features for insect species identification. The performance of the insect species classification is directly affected by the feature extraction step. All the methods mentioned above use deep learning approaches in both feature extraction and classification stages. In recent times, deep learning approaches have become increasingly popular in many areas. However, their major drawbacks are thought to be the substantial computational expense, the demand for many-dimensional input, and the costly hardware prerequisites. Consequently, the demand for hand-crafted approaches remains. The LBP is used to extract the spatial characteristics of grasshopper images. There are many variants of the LBP method. It has a strong discriminative ability and low computational complexity. While LBP has achieved significant performance in image processing, there is still a need for further exploration and investigation into its working principles. Numerous versions of LBP have been introduced in recent years. Several queries persist regarding LBP. One such inquiry involves understanding the extent to which the seemingly straightforward LBP feature conveys highly discriminative information about local structures. Additionally, there is a need to identify the information that may be lacking in the LBP feature and determine methods to articulate imperfect data

within the LBP framework. In this study, the neutrosophic theory is combined with LBP. The neutrosophic theory plays a crucial role in differentiating the boundary areas among distinct texture motifs. It involves examining details on a small and subtle scale.

The aim of this paper is to propose an innovative hybrid approach based on neutrosophic set theory for the characterization of intra and interclass variations in grasshopper species classification. Additionally, the paper aims to introduce a novel open Grasshopper Classification Dataset (GHCD11) to facilitate research and development in the field of automated grasshopper species classification. For this reason, the neutrosophic completed local binary pattern (CLBP) is used to solve this problem and to increase classification accuracy.

2. Material and Methods

2.1. Material

The proposed dataset consists of 11 different types of grasshopper species imaged in the Southeast region of Turkey. This study mainly focuses on classifying grasshopper species using unique features and machine learning techniques based solely on a photo of the grasshopper. We have collected 28 images for each grasshopper species class. Each grasshopper image has different scale, size, rotation, shapes, backgrounds, and views. It is difficult to identify because of these variances.

2.1.1. Dataset

Calliptamus italicus, a species that damages plant crops in many parts of Turkey and has a swarm forming feature, caused regional damage to many agricultural lands in the Adakli district of Bingöl province in 2021 and caused economic loss (Qin et al. 2013; İlçin & Satar 2020; İlçin et al. 2021). *Dociostaurus maroccanus* species, known as the Moroccan locust, causes damage in areas such as gardens and orchards and is effective in many regions of Turkey, but it has been determined that it causes economic damage in the rural areas and cereal fields of the Bingöl Province (İlçin et al. 2021). It has been recorded that *Anacridium aegyptium* species, known as the corn locust, causes economic losses in cereals. *A. aegyptium*, which is a common species in the areas where cereals are grown in our country, is an important plant pest. *Tettigonia viridissima* species have been detected in the meadow, pasture, and cereal areas and are a common species locally. Although *Tettigonia caudata* species is omnivorous, it has the same genus as *T. viridissima* species and has typical similarities. This species causes damage, especially to cotton and alfalfa plants. *Truxalis robusta robusta* has been detected in many localities in the Eastern and Southeastern Anatolia regions, especially in wooded areas and in areas where cotton plants are dense. *Oedipoda miniata miniata* is one of the most common grasshopper species and it has been determined that it causes low damage in fields and gardens. *Notostaurus anatolica* is a species that could be recognized by the specific wing and leg bands collected in the nymph (instar) stage and its body patterns are unique. *Shistocerca gregaria* is one of the rare species of grasshoppers that have the ability to form swarms and spread over large areas, and according to the data of FAO, it caused 20.2 million people to face hunger in countries located on the African continent in 2020 (FAO 2020). It causes serious economic loss. *Pyrgodera armata* is a species with specific features in terms of the shape and color of its head and other body organs and is a grasshopper species whose damage status could not be determined. The locality was collected from the rural areas of Batman province, Southeastern Anatolia region. The species *Saga ephippigera ephippigera* is a predatory grasshopper known as the carnivorous grasshopper. It is an effective and useful grasshopper species observed in many places, especially in the Eastern and Southeastern Anatolian regions (İlçin & Satar 2018; İlçin 2019). Table 1 shows the sample images from 11 different grasshopper species.

Table 1- Details of the GHCD11 dataset

Grasshopper species	***Number of images***
Calliptamus italicus	672
Dociostaurus maroccanus	672
Anacridium aegyptium	672
Tettigonia viridissima	672
Saga ephippigera	672
Truxalis robusta	672
Oedipoda miniata miniate	672
Tettigonia caudata	672
Notostaurus anatolica	672
Schistocerca gregaria	672
Pyrgodera armata	672

2.1.2. Image resizing

Images in the dataset have different sizes. Every image has been resized to a 480 x 480 pixels size to standardize the image size and to trim down the computational expenses.

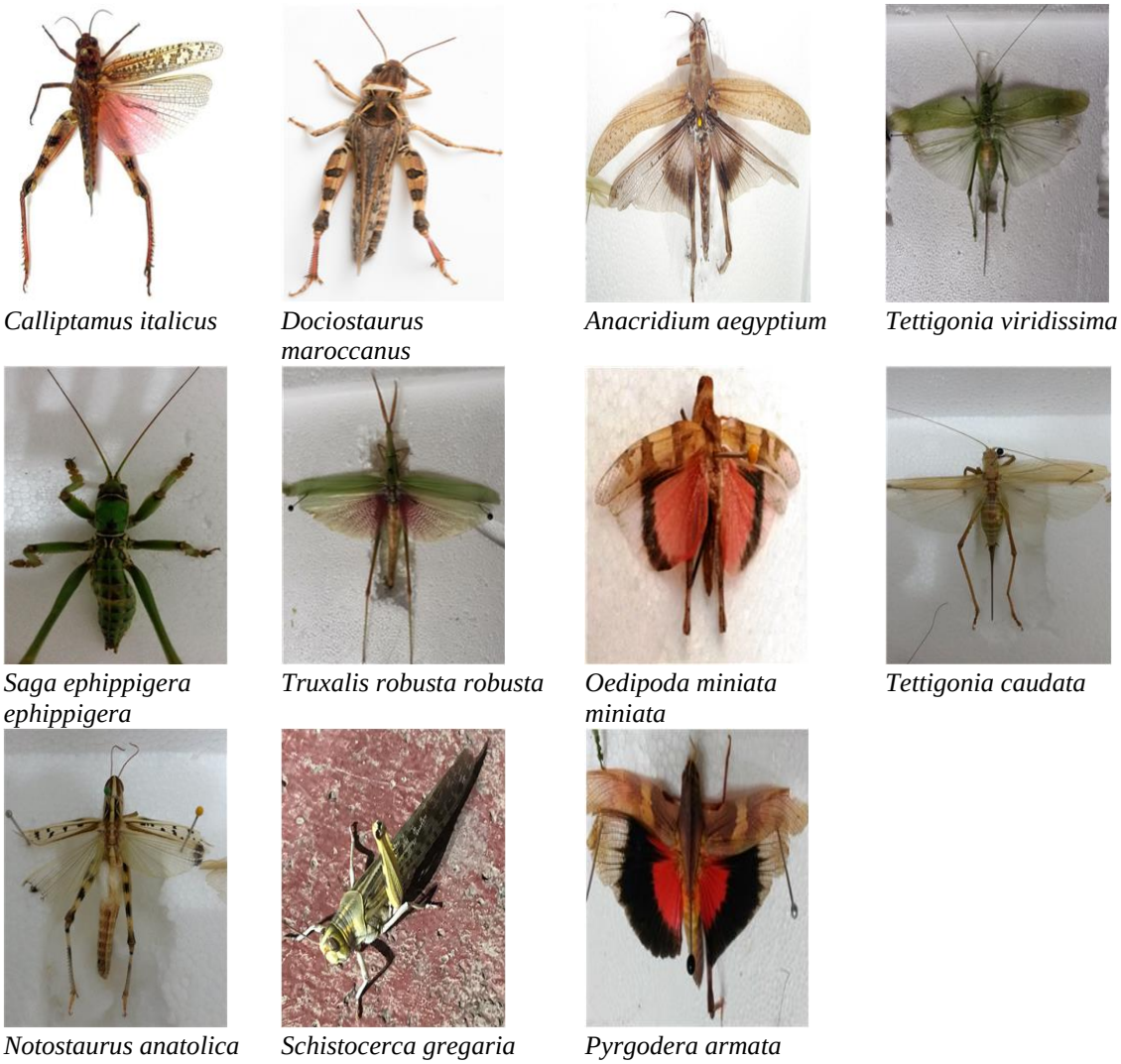

Figure 1- Sample images from 11 different grasshopper species

2.1.3. Data augmentation

In this paper, data augmentation is applied to artificially increase dataset size. It helps overcome the "not enough data" issue, prevents overfitting. The original dataset has 28 images for each grasshopper type. It is applied to the original dataset based on geometric transformations. Affine transformations are used in data augmentation to introduce variability to the training dataset. This helps prevent overfitting by exposing the model to a more diverse set of examples during training. Data augmentation through affine transformations, the model becomes more robust and generalizes better to variations present in real-world scenarios. The introduction of variations in the training data helps the model learn essential features and patterns without memorizing specific instances. The augmentations carried out via rotation, scaling, and reflection to enhance classification performance. The images in original dataset rotated by 45^{o} angles in the range [0, 360] degrees and resized images by 2 random scale factors in the range [1.2, 2.1]. Thus, the dataset's size is expanded to be 24 times larger through augmentation of the number of images. Table 1 expresses the count of images for each grasshopper species in GHCD11 dataset.

2.2. Methods

This paper introduces a grasshopper species classification framework based on neutrosophic set without high-cost extra operations. This feature is widely embraced for handling diverse types of uncertainties. Additionally, it considers both spatial and boundary information, effectively addressing and managing uncertainties. A thorough texture analysis is conducted by amalgamating various features inherent in locust images. The LBP method exhibits insufficient robustness to outer variables like noise and low contrast, thereby adversely impacting the feature extraction procedure. Unwanted elements like noise and fluctuations in light within the input locust image can influence the quality of features. Consequently, there is a risk of information loss, leading to a decrease in performance during classification stage. Effectively suppressing noise components through a neutrosophic set is crucial for precise edge detection and the extraction of effective features. It is imperative to guarantee the preservation of discriminative features in diverse image regions. Otherwise, the classification performance may suffer due to the

inability to extract these key features from the image. Failure to extract discriminative features from the image may result in a decline in classification performance.

2.2.1. Completed Local Binary Patterns (CLBP)

LBP encodes local texture information. To improve the LBP's performance in different textural situations, various variants are proposed (Ojala et al. 2002). The rotation, translation, and noise sensitivity make grasshopper image classification a difficult task. It's crucial to extract distinctive descriptors to effectively classify textures. The CLBP represents a modification of the LBP. It uses CLBP_M, CLBP_C, and CLBP_S operands as well as the local difference sign-magnitude transform (LDSMT). These three operands indicate the magnitude, center, and sign components (Guo et al. 2010). A general overview of the CLBP approach is shown in Figure 2. To express local patterns, the LBP only uses the sign vector. This could produce some inaccurate classification results. Compared to the magnitude components, the sign components are more accurate. Additionally, combining the sign and magnitude components yields significantly better results. The sign component conserves a lot of information about local differences. The magnitude component might offer additional discriminant data.

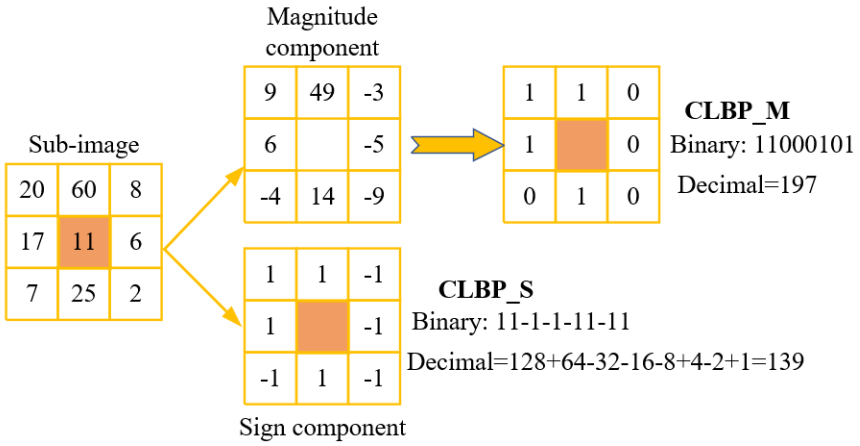

Figure 2- Illustration of completed local binary pattern

2.2.2. Neutrosophic set

The neutrosophic set (NS) theory looks into the nature and the extent of neutrality (Sengur et al. 2019). The degree of belonging is expressed using membership functions in standard fuzzy sets. In neutrosophy, every incident has an indeterminacy (*I*), falsity (*F*), and truth (*T*) level. The three memberships are utilized to determine an element's degree of *T*, *I*, and *F*. They are in [0, 1] interval. The degree of these functions could be used to quantify the uncertainty. The definitions of NS and uncertainty using NS were provided in (Alpaslan 2022).

The neutrosophic transformations of sample grasshopper images (*Calliptamus italicus*, *Dociostaurus maroccanus*) are demonstrated in Figure 3.

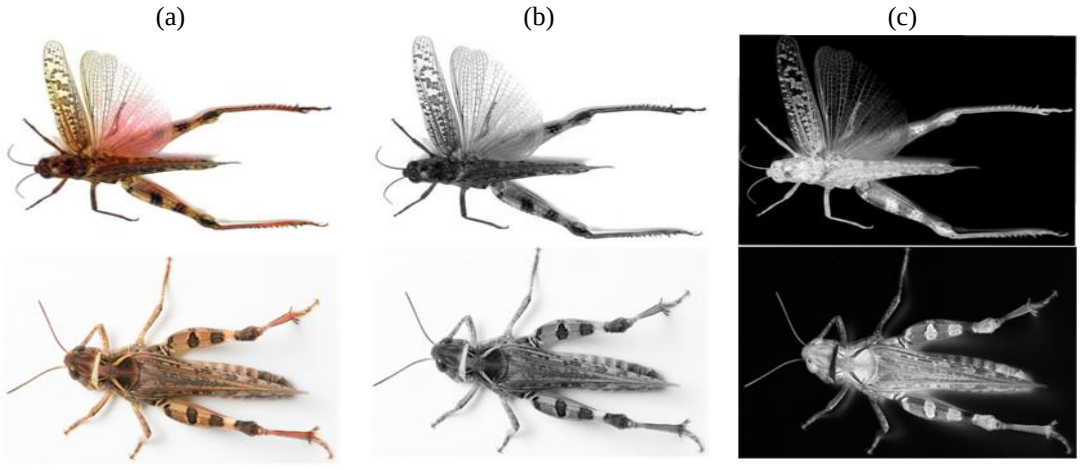

Figure 3- Subset of grasshopper images in the neutrosophic field. (a) Input image, (b) *T* (c) *F* sets

2.2.3. neutroCLBP

The local texture is encoded by most of the texture analysis methods in the literature. Unfortunately, these approaches do not successfully capture the boundaries. Additionally, the conventional methods are unable to eliminate the ambiguities in an image. Because they do not have any uncertainty management instruments. The neutroCLBP method could overcome these limitations without high-cost extra operations. The *T* and *F* sets in the neutrosophic field were used to characterize the grasshopper images. The *F* set was utilized with the *T* set in neutroCLBP. As a result, the complementary use of both false and truth components improves the LBP's distinctiveness.

There are two key stages in neutroCLBP. The input images are converted to neutrosophic field in the first stage. The second stage eliminates the deficiency of *I* set using LBP's local texture analysis capabilities. The neutroCLBP method makes advantage of the neutrosophic set and the CLBP's statistical texture analysis capabilities to suppress the image's noise. As a result, inter-class similarities and intra-class variations in grasshopper images are more defined. The neutroCLBP consists of three main stages: (1) neutrosophic components calculation, (2) extraction of neutroCLBP-M and neutroCLBP-S features, (3) cross-scale joint coding and histogram conjunction. The $neutroCLBP-M^{h}_{(P,R)}$ gives better results. For this reason, the $neutroCLBP-M^{h}_{(P,R)}$ was used in this study. The frame diagram of neutroCLBP is shown in Figure 4 (Alpaslan 2022).

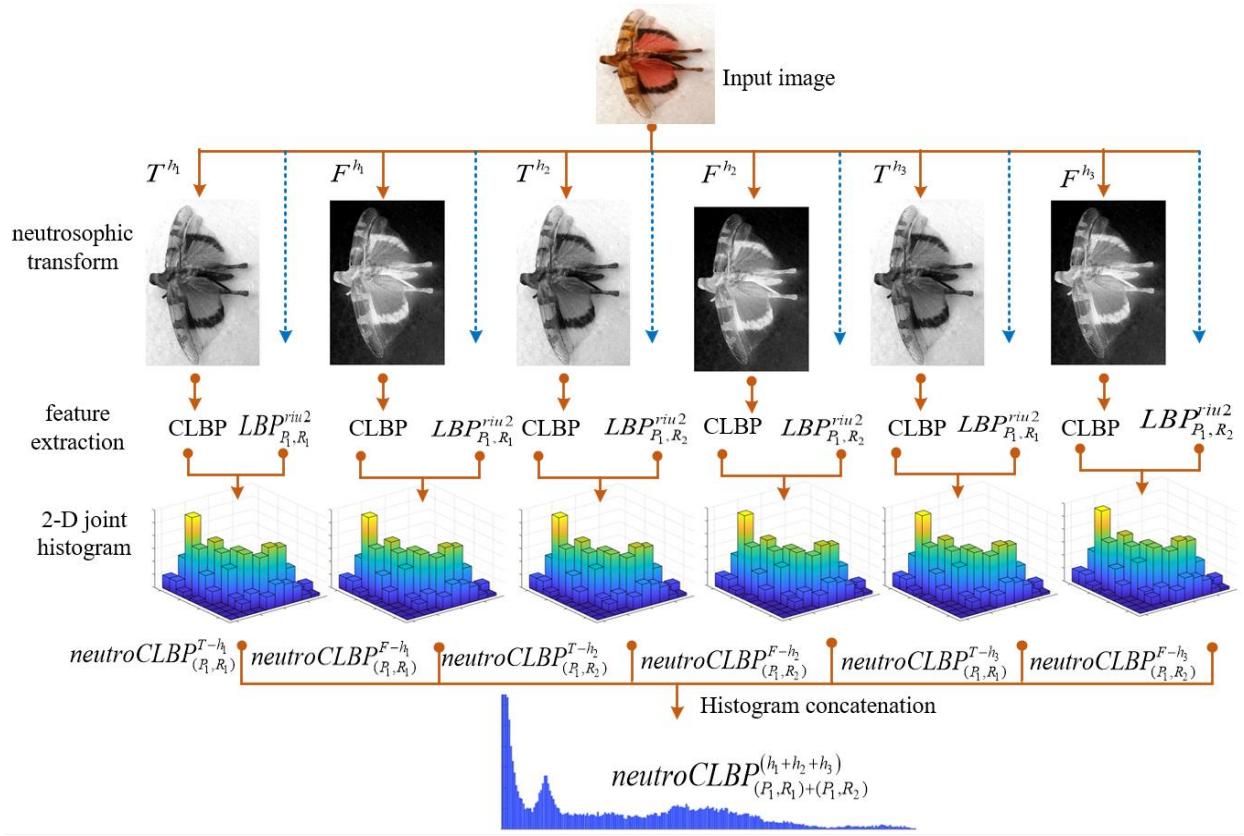

Figure 4- Calculation of neutroCLBP features

In order to encode neutrosophic membership components, the $LBP^{riu2}_{P,R}$ and the CLBP are combined (El Merabet et al. 2019). As a result, the CLBP_C features of *T* and *F* components were calculated.

The neutrosophic components of the grasshopper image are computed using various parameters. Various (*P*,*R*) and *h* values are used in multi-resolution texture analysis. The diameter of filters is determined with three different *h*. The radius *R* is also used for reduction of feature dimension of the neutroCLBP. The cross-scale joint coding is carried out as follows:

1) $LBP^{riu2}_{P,R}$ and $CLBP\left(x_c, y_c\right)^{riu2\_h}_{P,R}$ of T^{h_1} with (P_1,R_1) and h_1 are merged. The result is showed as $neutroCLBP\left(x_c, y_c\right)^{T-h_1}_{P_1,R_1}$.
2) $LBP^{riu2}_{P,R}$ and $CLBP\left(x_c, y_c\right)^{riu2\_h}_{P,R}$ of F^{h_1} with (P_1,R_1) and h_1 are merged. The result is showed as $neutroCLBP\left(x_c, y_c\right)^{F-h_1}_{P_1,R_1}$.
3) In $CLBP^{h_1}_{P_1,R_1}$ of T^{h_1}, h_1 is changed with h_2, and novel statement is denoted as $neutroCLBP^{T-h_2}_{P_1,R_1}$.

4) In $CLBP_{P_1,R_1}^{h_1}$ of F^{h_1}, h_1 is changed with h_2, and novel statement is denoted as $neutroCLBP_{P_1,R_1}^{F-h_2}$

5) $neutroCLBP(x_c, y_c)_{P_1,R_1}^{F-h_1}$, $neutroCLBP_{P_1,R_1}^{F-h_2}$, $neutroCLBP_{P_1,R_2}^{T-h_2}$ and $neutroCLBP_{P_1,R_2}^{T-h_3}$ are concatenated to construct the multi-resolution structure. This structure is denoted as $neutroCLBP_{(P_1,R_1)+(P_1,R_2)}^{(h_1+h_2+h_3)}$.

3. Experimental Results

Several experiments have been carried out to validate the effectiveness of the neutroCLBP on grasshopper species classification. The nearest neighbor (1-NN) and support vector machines (SVM) classifier were used to demonstrate the discriminative ability of the method (Gul et al. 2021). The one-versus-one approach and cubic kernel function were employed in our experimental studies. The SVM model performs noticeably better when nonlinear kernels are used in complicated problems. The 30% and 70% of the dataset were used for testing and training, respectively. Additionally, 5-fold cross-validation was applied.

The GHCD11 dataset was utilized in the first experiment to assess the effects of various parameters. The accuracy is used in experiments. The calculation for accuracy is shown in Eq (1).

$$accuracy = \frac{1}{p}\sum_{i=1}^{p}\frac{TP_i + TN_i}{TP_i + TN_i + FP_i + FN_i} \quad (1)$$

Where; *TP*, *TN*, *FP*, *FN* and *p* denotes the number of true positives, true negatives, false positives, false negatives, and classes respectively.

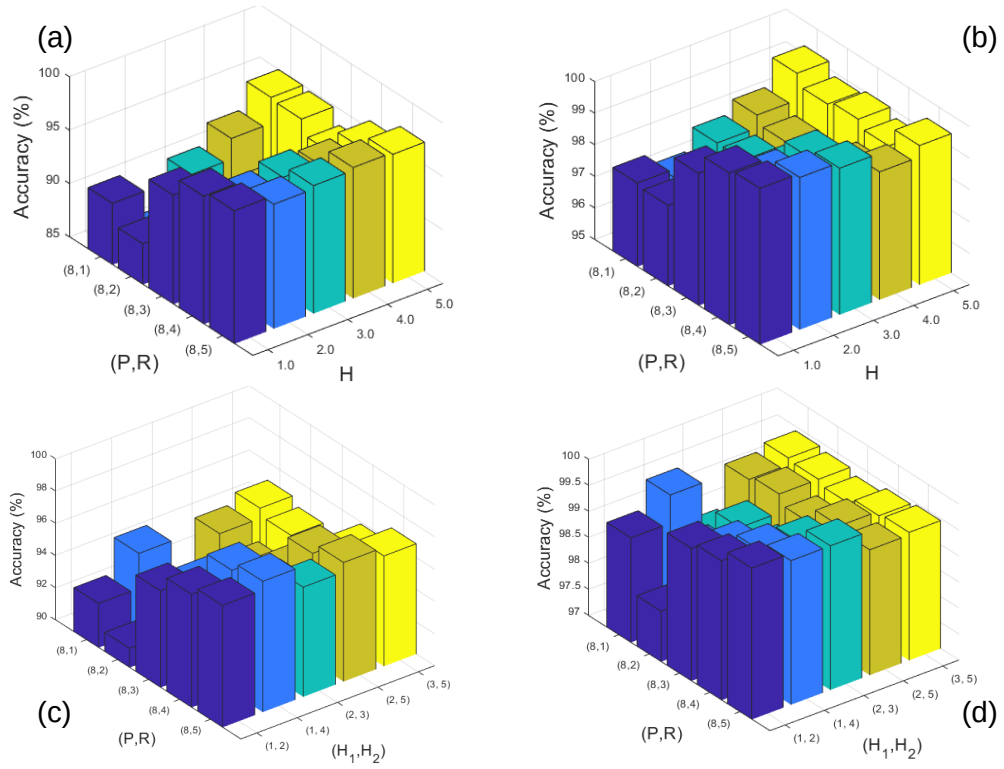

Figure 5- Experimental results (%) of $neutroCLBP_{(P,R)}^{h}$ for (a) kNN and (b) SVM classifier and $neutroCLBP_{(P_1,R_1)}^{h_1+h_2}$ for (c) kNN and (d) SVM classifiers

The experimental studies were carried out with Intel Xeon(R) E3-1241 v3 CPU, and 8 GB of RAM.

3.1. Analysis of neutroCLBP parameters

There are three different parameters in the $neutroCLBP^{h}_{(P,R)}$. These parameters are *h*, *R* and *P*. The *h* refers to neutrosophic filter; *R* refers to sampling radius; and *P* refers to sampling neighborhood. The *P* is fixed as 8 to lower the dimension and execution time. The *h* parameter determines the radius of filters. It is selected to detect statistical details in boundaries. The image is blurred and loses pixel brightness and textural variety when the *h* parameter is quite high. The filtered image is prone to noise if it is selected too small. In this paper, multi-scale texture analysis and investigation of optimal *h* parameter for grasshopper species classification have been carried out. Neutrosophic set noise suppression and enhancement of grasshopper images have positive impact on the classification performance. The method is analyzed with various *h* and *R* values ranging from 1 to 5.

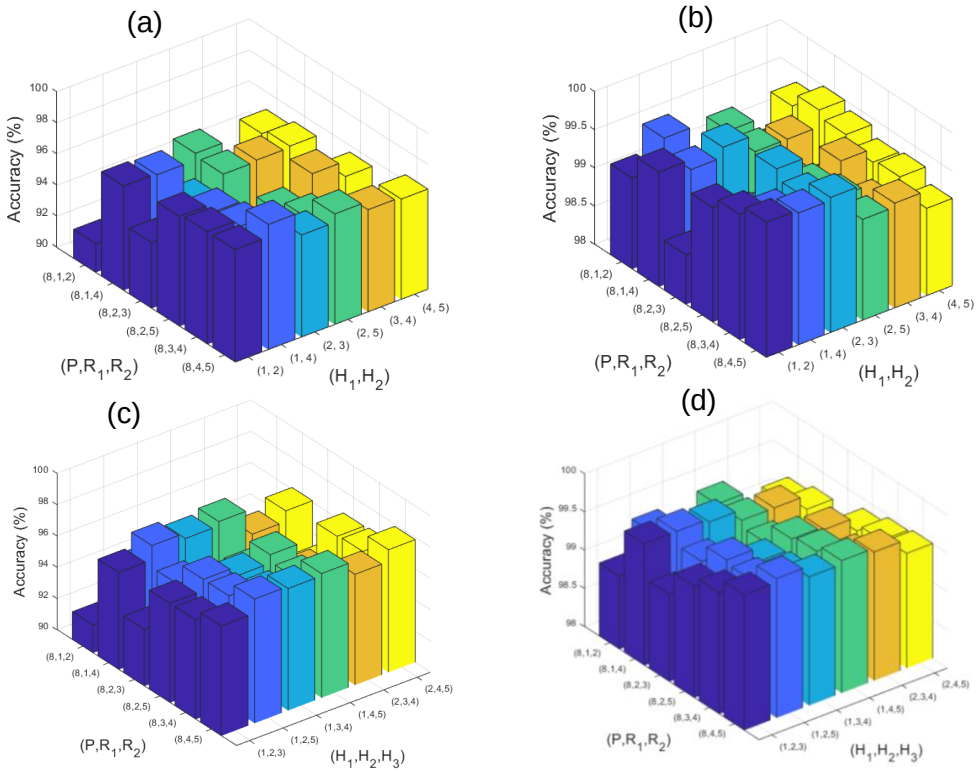

Figure 6- Experimental results (%) of $neutroCLBP^{h_1+h_2}_{(P_1,R_1)+(P_1,R_2)}$ for (a) kNN and (b) SVM classifiers and $neutroCLBP^{h_1+h_2+h_3}_{(P_1,R_1)+(P_1,R_2)}$ for (a) kNN and (b) SVM

The impact of *h* and *R* parameters were studied on classification performance using GHCD11 dataset. Firstly, the effects of these parameters on the $neutroCLBP^{h}_{(P,R)}$ were investigated. The most favorable outcomes were achieved with *R*=5 as shown in Figure 5. Additionally, it has been seen that the accuracy increases with *R* value. The best results were obtained with *R*=5 and *h*=1 parameters in $neutroCLBP^{h}_{(P,R)}$ for both 1-NN and SVM classifiers. The most favorable outcomes were achieved with *R*=5 and $h_1 = 1$, $h_2 = 4$ parameters in $neutroCLBP^{h_1+h_2}_{(P_1,R_1)}$ for 1-NN classifier. The best results were obtained with $h_1 = 1$, $h_2 = 4$ parameters in $neutroCLBP^{h_1+h_2}_{(P_1,R_1)}$ for SVM classifier. It is seen from Figure 5 that, the use of more than one *h* parameter increases the classification accuracy by 3.41% for 1-NN classifier and by 2.06% for 1-NN classifier on average. It is also clear from Figure 5 that the SVM classifier gives 7.77% better results than the 1-NN classifier on average.

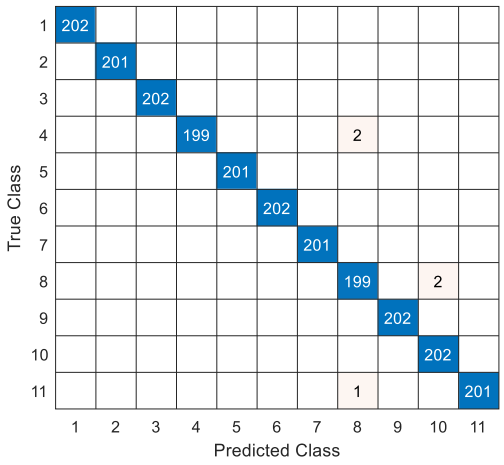

Figure 7- Confusion matrix for $neutroCLBP^{h_1+h_2+h_3}_{(P_1,R_1)+(P_1,R_2)}$

A confusion matrix is provided to demonstrate the multi-resolution $neutroCLBP^{h_1+h_2+h_3}_{(P_1,R_1)+(P_1,R_2)}$'s accuracy in a more thorough description in classifying grasshopper species as shown in in Figure 7.

Table 2- The comparison of the neutroCLBP with state-of-the-art deep learning models

Model	*Reference*	*Feature Size*	*Accuracy*
VGG16	Simonyan & Zisserman 2014	25.088	97.97
VGG19	Simonyan & Zisserman 2014	25.088	97.83
ResNet50	He et al. 2015	100.352	91.38
ResNet152	He et al. 2015	100.352	98.44
MobileNet	Sandler et al. 2018	50.176	97.78
DenseNet121	Huang et al. 2016	50.176	97.78
DenseNet169	Huang et al. 2016	81.536	99.34
DenseNet201	Huang et al. 2016	94.080	99.24
neutroCLBP	This paper	600	**99.77**

The proposed framework was evaluated with hand-crafted and deep learning-based approaches. Table 2 shows the comparison of the *neutroCLBP* method with current deep learning models. The *neutroCLBP* gives 99.77% classification accuracy on GHCD11 dataset. It is seen from Table 2 and 3 that, deep learning-based approaches yield better outcomes than other hand-crafted methods. However, the proposed framework was outperformed deep learning methods with reasonable computational cost. All models were trained utilizing stochastic gradient descent (SGD) method employing a batch size of 8, 50 epochs, 0.0001 learning rate and Adam optimization. DenseNet169 model gave the closest results. It is clear from Figure 8 that, the *neutroCLBP* shows high performance with low time complexity. The training times of *neutroCLBP* and different deep learning models were compared. VGG16 (Simonyan & Zisserman 2014), VGG19 (Simonyan & Zisserman 2014), ResNet50 (He et al. 2015), ResNet152 (He et al. 2015), MobileNet (Sandler et al. 2018), DenseNet121 (Huang et al. 2016), DenseNet169 (Huang et al. 2016), DenseNet201 (Huang et al. 2016) models were used for time comparison. The proposed methodology is about 40 times faster than the MobileNet, the fastest model, and about 152 times faster than the ResNet152, the slowest model. Besides, deep learning models require graphics cards with a significant amount of computing power. The proposed methodology has both higher classification accuracy and lower time complexity than deep learning models. Experimental results show that the proposed methodology is suitable for real-time applications. The experiments in Table 2 and Figure 8 were carried out with Intel i9 Intel Core i9-11900K CPU, GeForce RTX™ 3080 Ti graphics cards, and 64 GB of RAM.

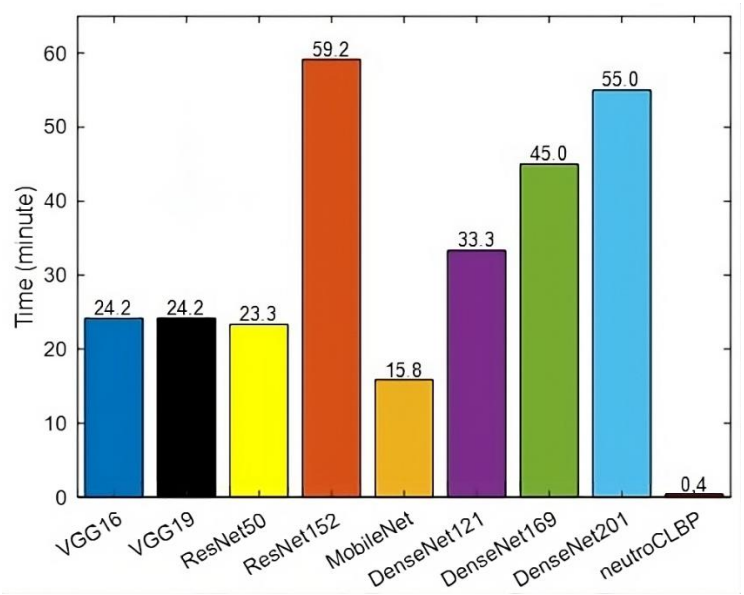

Figure 8- Comparison of models training time

Table 3- The comparison of *neutroCLBP* using current approaches on the GHCD11 dataset

Method	*Reference*	*Accuracy*
LBP	Ojala et al. 1996	89.35
CLBP_M	Guo et al. 2010	89.94
CLBP_S	Guo et al. 2010	90.44
LCvMSP	El Merabet & Ruichek 2018	95.67
LCxMSP	El Merabet & Ruichek 2018	93.59
RLBGC	El Khadiri et al. 2018	95.26
ALBGC	El Khadiri et al. 2018	96.62
ACS-LBP	El Merabet et al. 2019	98.92
LDTP	El khadiri et al. 2018	79.97
neutroCLBP	This paper	**99.77**

The classification performance of $neutroCLBP^{h_1+h_2}_{(P_1,R_1)+(P_1,R_2)}$ and $neutroCLBP^{(h_1+h_2)+(h_2+h_3)}_{(P_1,R_1)+(P_1,R_2)}$ were investigated from many aspects in the second experiment. The $neutroCLBP^{(h_1+h_2)+(h_2+h_3)}_{(P_1,R_1)+(P_1,R_2)}$ was evaluated with three *h* and two *R* values. The $neutroCLBP^{h_1+h_2}_{(P_1,R_1)+(P_1,R_2)}$ was evaluated with two *h* and two *R* values. A multi-scale analysis was conducted since the neutrosophic components were obtained for multiple *h* values. The GHCD11 database contains different types of grasshoppers. Figure 6 shows the classification accuracy results of $neutroCLBP^{h_1+h_2}_{(P_1,R_1)+(P_1,R_2)}$ and $neutroCLBP^{h_1+h_2+h_3}_{(P_1,R_1)+(P_1,R_2)}$ features for both kNN and SVM classifiers. The best results were obtained with $R_1=4, R_2=5$ and $h_1=1,\ h_2=2$ parameters in $neutroCLBP^{h_1+h_2}_{(P_1,R_1)+(P_1,R_2)}$ for the SVM classifier. The best results were obtained with $R_1=4, R_2=5$ and $h_1=1,\ h_2=2,\ h_3=3$ parameters in $neutroCLBP^{(h_1+h_2)+(h_2+h_3)}_{(P_1,R_1)+(P_1,R_2)}$ for the SVM classifier. It is seen from Figure 6 that, the use of more than one parameter increases the classification accuracy. Besides, the $neutroCLBP^{(h_1+h_2)+(h_2+h_3)}_{(P_1,R_1)+(P_1,R_2)}$ gives slightly better classification results than $neutroCLBP^{h_1+h_2}_{(P_1,R_1)+(P_1,R_2)}$. However, its computational complexity is high. Experimental results show that multi-scale features yielded superior results.

4. Discussion

Diagnosis and identification processes for insects include many features; It could consist of very complex and controversial applications carried out within the framework of the examination and interpretation of morphological, physiological, genital, and other molecular markers. Although the margin of error increases in the diagnostics and definitions that are made sometimes, the misuse of the diagnostic keys could prolong the process and misdiagnoses could lead to an inevitable situation. Traditional predictive diagnostic methods are only limited by the data they have. Therefore, collecting and obtaining data is difficult. However, for new researchers or young researchers interested in insects, the use of more professional diagnostic tools could provide solutions to many important problems. With this study, it will be possible to carry out species-diagnostic applications of

high accuracy and clear information in the determination of many agricultural pests, especially insects. In addition, it will prevent the emergence of erroneous applications with time and wrong results in diagnosis. With the created digital application, one of the main results is to prevent the damage they will cause by identifying and learning about many plant pests, especially grasshoppers. Some of the other very important results are; It seems possible to provide guidance for teaching purposes, data-forecasting, agricultural practices, and pesticide use.

The following are the paper's main contributions: A large dataset containing 11 different types of grasshopper species, named the GHCD11. It consists of mix of images with different scale, size, rotation, shapes, backgrounds, and views. In this way, any classification algorithm could be strong enough to deal with these challenges. A novel methodology that could classify the grasshopper species with high accuracy is proposed. The proposed methodology consists of various stages. The grasshopper images are first converted to neutrosophic field in the first stage. Thus, stronger features are obtained. Additionally, a cross-scale joint approach is used to integrate these discriminatory features with rotation invariant LBP features. The proposed methodology has both higher classification accuracy and lower time complexity than deep learning models. The proposed methodology could achieve up to 99.7% classification accuracy even while working with challenging dataset of wide range in image scale, rotation, and size. It does not require high-powered expensive graphics cards. Besides, grayscale grasshopper images exhibit greater resilience to noise in the neutrosophic domain. The presence of neutrosophic components plays a role in noise suppression, leading to a more accurate detection of edges. The proposed approach guarantees the extraction of more robust features. This marks the inaugural integration of neutrosophic set theory and the LBP method into an insect species identification system through extensive state-of-the-art research. The method put forth demonstrates resilience in the face of challenges such as noise, rotation, and variations in lighting conditions.

5. Conclusions

Species identification in grasshoppers has traditionally been based on body organs (cephalo, thorax, and abdomen) and genital organs (genital plate). There is no automatic grasshopper species identification system available yet. In this study, many plant pests and other insect species (grasshoppers, etc.) have been detected by image processing and machine learning methods. The CLBP method undergoes reinterpretation through the lens of the neutrosophic set, leading to the development of a novel feature extraction approach that leverages neutrosophic set components. The outcome is an image imbued with enhanced significance, achieved through the mitigation of noise effects. Besides, the *neutroCLBP* based grasshopper classification framework is proposed. In this framework, the neutrosophic membership components of the grasshopper image were utilized. In this way, noise effects were minimized, and a more informative image was generated. The proposed framework has remarkable performance with acceptable computational expense. The experiments represent that the proposed framework could accurately classify grasshopper species. The comparative experiments show that the *neutroCLBP* improves the classification accuracy of LBP-based current handcrafted features at least about 1% and at most about 11% thanks to the hybrid approach. Besides, the multi-scale strategy positively affected discrimination of the grasshopper images with high intra-class variation and inter-class similarity. The average accuracy is up to 99.77%, which is higher than VGG16, VGG19, ResNet50, ResNet152, MobileNet, DenseNet121, DenseNet169, DenseNet201 models with reasonable computational cost. The proposed framework could also used for education in plant protection.

Declarations

Conflicts of Interest: No conflict of interest was declared by the authors.

Declaration of Ethical Standards: The authors of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

Author Contributions: Study conception and design: NA, Mİ; data collection: Mİ; software, methodology: NA; analysis and interpretation of results: NA, Mİ; draft manuscript preparation: NA, Mİ. All authors reviewed and approved the final version of the manuscript.

References

Alpaslan N (2022). Neutrosophic set based local binary pattern for texture classification. Expert Systems with Applications 209: 118350. - doi: 10.1016/J.ESWA.2022.118350

Cheng X, Zhang Y, Chen Y, Wu Y & Yue Y (2017). Pest identification via deep residual learning in complex background. Computers and Electronics in Agriculture 141: 351–356

Chudzik P, Mitchell A, Alkaseem M, Wu Y, Fang S, Hudaib T, Pearson S & Al-Diri B (2020). Mobile Real-Time Grasshopper Detection and Data Aggregation Framework. Scientific Reports 2020 10:1. 10: 1–10. - doi: 10.1038/s41598-020-57674-8

Collett R A & Fisher D O (2017). Time-lapse camera trapping as an alternative to pitfall trapping for estimating activity of leaf litter arthropods. Ecology and Evolution 7: 7527–7533

Ding W & Taylor G (2016). Automatic moth detection from trap images for pest management. Computers and Electronics in Agriculture 123: 17–28. - doi: 10.1016/J.COMPAG.2016.02.003

El Khadiri I, Chahi A, El Merabet Y, Ruichek Y& Touahni R (2018). Local directional ternary pattern: A New texture descriptor for texture classification. Computer Vision and Image Understanding 169: 14–27

El Khadiri I, Kas M, El Merabet Y, Ruichek Y& Touahni R (2018). Repulsive-and-attractive local binary gradient contours: New and efficient feature descriptors for texture classification. Information Sciences 467: 634–653. - doi: 10.1016/J.INS.2018.02.009

El Merabet Y& Ruichek Y (2018). Local Concave-and-Convex Micro-Structure Patterns for texture classification. Pattern Recognition 76: 303–322. - doi: 10.1016/J.PATCOG.2017.11.005

El Merabet Y, Ruichek Y& el idrissi A (2019). Attractive-and-repulsive center-symmetric local binary patterns for texture classification. Engineering Applications of Artificial Intelligence 78: 158–172

Engel J, Hertzog L, Tiede J, Wagg C, Ebeling A, Briesen H, Weisser W W, Engel C, Hertzog L, Tiede J, Wagg C, Ebeling A, Briesen H& Weisser W W (2017). Pitfall trap sampling bias depends on body mass, temperature, and trap number: insights from an individual-based model. Ecosphere 8: e01790.

FAO | Food and Agriculture Organization of the United Nations (2020). Desert Locust Upsurge.

Gul E, Alpaslan N & Emiroglu M E (2021). Robust optimization of SVM hyper-parameters for spillway type selection. *Ain Shams Engineering Journal* 12: 2413–2423. - doi: 10.1016/J.ASEJ.2020.10.022

Gullan P & Cranston P (2014). The insects: an outline of entomology. John Wiley & Sons.

Guo Z, Zhang L& Zhang D (2010). A completed modeling of local binary pattern operator for texture classification. IEEE Transactions on Image Processing 19: 1657–1663

Hansen O L P, Svenning J C, Olsen K, Dupont S, Garner B H, Iosifidis A, Price B W & Høye T T (2020). Species-level image classification with convolutional neural network enables insect identification from habitus images. Ecology and Evolution 10: 737–747

He K, Zhang X, Ren S& Sun J (2015). Deep Residual Learning for Image Recognition. In: Proceedings of the IEEE Computer Society Conference on Computer Vision and Pattern Recognition. IEEE Computer Society, Vol. 2016-December

Huang G, Liu Z, van der Maaten L & Weinberger K Q (2016). Densely Connected Convolutional Networks. In: 30th IEEE Conference on Computer Vision and Pattern Recognition. Institute of Electrical and Electronics Engineers Inc., Vol. 2017-January

İlçin M (2019). Investigation of Orthoptera: Insecta Fauna of Useful, Harmful and Predator Species in the Batman Region (Turkey). Science Stays True Here" Biological and Chemical Research 6: 30–40

İlçin M & Satar A (2018). On the Orthopteran Fauna (Insecta: Orthoptera) of Agricultural Regions of Batman Province (Turkey). Boletín de la Sociedad Entomológica Aragonesa (SEA) 62: 163-166

İlçin M & Satar A (2020). Dociostaurus (Dociostaurus) maroccanus Thunberg, 1815 (Acrididae:Orthoptera) Türünün Sürü Oluşturma ve Bitkilere Zarar Durumunun Araştırılması. *Turkish Journal of Nature and Science* 9: 80–83

İlçin M, Satar A & Balkaya A (2021). Remarks on the outbreak of Calliptamus italicus Linnaeus, 1758 (Acrididae: Orthoptera) in Bingöl province, Turkey., pp. 259–261. Retrieved from https://www.researchgate.net/publication/357480371

Kasinathan T, Singaraju D & Uyyala SR (2021). Insect classification and detection in field crops using modern machine learning techniques. Information Processing in Agriculture 8: 446–457

Liu L, Wang R, Xie C, Yang P, Wang F, Sudirman S & Liu W (2019). PestNet: An End-to-End Deep Learning Approach for Large-Scale Multi-Class Pest Detection and Classification. IEEE Access 7: 45301–45312

Liu Z, Gao J, Yang G, Zhang H, He Y (2016). Localization and Classification of Paddy Field Pests using a Saliency Map and Deep Convolutional Neural Network. Scientific Reports 2016 6:1. 6: 1–12

Martineau M, Conte D, Raveaux R, Arnault I, Munier D & Venturini G (2017). A survey on image-based insect classification. Pattern Recognition 65: 273–284

Nanni L, Manfè A, Maguolo G, Lumini A & Brahnam S (2022). High performing ensemble of convolutional neural networks for insect pest image detection. Ecological Informatics 67: 101515

Norouzzadeh M S, Nguyen A, Kosmala M, Swanson A, Palmer M S, Packer C & Clune J (2018). Automatically identifying, counting, and describing wild animals in camera-trap images with deep learning. Proceedings of the National Academy of Sciences of the United States of America 115: E5716–E5725.

Ojala T, Pietikäinen M & Harwood D (1996). A comparative study of texture measures with classification based on featured distributions. Pattern Recognition 29: 51–59

Ojala T, Pietikainen M & Maenpaa T (2002). Multiresolution gray-scale and rotation invariant texture classification with local binary patterns. IEEE Transactions on Pattern Analysis and Machine Intelligence 24: 971–987

Qin Y, Li Z, Zhao L, Fowler G, Fang Y (2013). The current and future potential geographical distribution of the Italian Locust, Calliptamus italicus (Linnaeus) (Orthoptera: Acrididae) in China. IFIP Advances in Information and Communication Technology 393 AICT: 290–298

Sandler M, Howard A, Zhu M, Zhmoginov A & Chen L C (2018). MobileNetV2: Inverted Residuals and Linear Bottlenecks. In: Proceedings of the IEEE Computer Society Conference on Computer Vision and Pattern Recognition. IEEE Computer Society

Sengur A, Budak U, Akbulut Y, Karabatak M & Tanyildizi E (2019). A survey on neutrosophic medical image segmentation. In: Neutrosophic Set in Medical Image Analysis

Simonyan K & Zisserman A (2014). Very Deep Convolutional Networks for Large-Scale Image Recognition. In: 3rd International Conference on Learning Representations. International Conference on Learning Representations, ICLR

Sinev S Y (2012). Coordinating the Traditional and Modern Approaches in the Systematics of Insects. Original Russian Text © S.Yu. Sinev. 92: 821–832

Skvarla M J, Larson J L & Dowling A P G (2014). Pitfalls and preservatives: a review. *The Journal of the Entomological Society of Ontario*. 145 pp

Sreedevi K, Meshram N & Shashank P R (2015). Insect Taxonomy—Basics to Barcoding. New Horizons in Insect Science: Towards Sustainable Pest Management pp. 3–12

Valan M, Makonyi K, Maki A, Vondráček D, Vondráček V & Ronquist F (2019). Automated taxonomic identification of insects with expert-level accuracy using effective feature transfer from convolutional networks. Systematic Biology 68(6): 876-895

Xia D, Chen P, Wang B, Zhang J & Xie C (2018). Insect Detection and Classification Based on an Improved Convolutional Neural Network. Sensors 2018, Vol. 18, Page 4169. 18: 4169

Xie C, Wang R, Zhang J, Chen P, Dong W, Li R, Chen T & Chen H (2018). Multi-level learning features for automatic classification of field crop pests. Computers and Electronics in Agriculture 152: 233–241

Zhang L, Lecoq M, Latchininsky A & Hunter D (2019). Locust and Grasshopper Management. https://doi.org/10.1146/annurev-ento-011118-112500 64: 15–34
Zhang Z (2011). Animal biodiversity: An outline of higher-level classification and survey of taxonomic richness. Magnolia press

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Characterization and Pathogenicity of Botryosphaeriaceae Species Associated with Gummosis, Dieback, Trunk and Branch Cankers of Almond Trees in Türkiye

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ABSTRACT
Members of Botryosphaeriaceae family with 25 genera and several species are spread over a wide range of lands and climates worldwide. They cause gummosis, decline, dieback and blight on many woody plants. The purpose of present study was to diagnose the pathogens linked to the aforementioned symptoms on almond trees in seven orchards of Yozgat province (Türkiye) with a DSb type climate (Hot humid continental - Köppen Geiger system of climatic classification). These trees displayed dieback, gummosis trunk and branch canker symptoms. They were identified by cultural and morphological characteristics, and compared by sequencing of the ITS regions, EF-1α and β-tubulin genes with those of other species in GenBank (NCBI). Based on the colony and conidial characteristics, 72 isolates were identified as *Diplodia seriata, Lasiodiplodia theobromae, Neofusicoccum parvum* and *Botryosphaeria dothidea*. Pathogenicity tests were succesfully realized on two-year-old almond cv: Ferradual seedlings using Koch's postulates. According to current data, *B. dothidea* was identified for the first time on almond trees in Türkiye. Accurate identification, prevalence and incidence of the pathogens are crucial for developing effective disease management strategies to prevent disease outbreaks in Türkiye.

Keywords: *Botryosphaeria*, Cultural characteristics, Molecular identification, *Prunus dulcis*

1. Introduction

The production and consumption of almonds (*Prunus dulcis* - family Rosaceae, Prunoideae, subfamily) has risen significantly during the last decade worldwide (Özdemir et al. 2022; Romero-Cuadrado et al. 2023a). Almond plant is more tolerant to different types of edaphic stresses; paradoxically it is more sensitive to stresses related to harsh climatic conditions (delayed spring frost and drought etc.) (Yeniay & Şık 2022). Therefore, it is desired to grow almond varieties that are resistant to these problems. (Freitas et al. 2023; Küçükyumuk & Suarez 2023). Türkiye is among the almond producing countries, ranking 4th in the world in 2022 (FAO 2022). Therefore, correct and effective disease management is inevitable to obtain the desired quantity and quality of almond production (Holland et al. 2021). Dieback in almond tree is usually caused by many biotic and abiotic stress factors (Ören et al. 2020; Goura et al. 2023). This requires correct identification of the problem (Avenot et al. 2022). Fungal pathogens present in soil and air, especially belonging to the Botryosphaeriaceae family is thought to have a major role in the dieback, gummosis, trunk or branch canker on almond trees (Olmo et al. 2016; Moral et al. 2019; Sohrabi et al. 2020). The previous studies reported dieback, gummosis and trunk or branch canker symptoms on almond trees in Türkiye (EFSA Panel on Plant Health et al. 2023) like Özer et al. (2022), who reported *Lasiodiplodia theobromae* and Kayım et al. (2015), who reported *Diplodia seriata* and *Neofusicoccum parvum* as fungal causal agents belonging to Botryosphaeriaceae family on almond trees. These are mostly prevalent in tropical, subtropical and temperate regions (Garcia et al. 2021; Silva-Valderrama et al. 2024). Grape (*Vitis vinifera*), peach (*Prunus persica* L.), plum (*Prunus salicina*), almond (*Prunus dulcis* (Mill.) and walnut (*Juglans regia*) are among some important hosts in this family responsible causing economic losses in Türkiye (Endes et al. 2016; Endes & Kayım 2022a; Çiftçi et al. 2023).

Field diagnosis of Botryosphaeriaceae species associated with on tree symptoms is frequently carried out by either producers or technical based on symptoms such as dieback, gummosis, trunk or branch canker, shoot, fruit and bud blight (Ezra et al. 2017; Moral et al. 2019; Antón-Domínguez et al. 2023). However, the above-mentioned symptoms fail to clearly distinguish the causal agents (Nouri et al. 2018; Holland et al. 2021). Therefore, asexual (anamorph) reproductive structures of these fungi are used for identification relying on cultural and morphological or physical characteristics of the mycelium formed by the respective fungus on agar solidified medium, to observe physical properties of the fungus such as colour, shapes of colony, the size and the structure of conidia (Avenot et al. 2022). This has risk of contamination with several anamorphic genera within the Botryosphaeriaceae

family along with the inadequacy of reliable morphological characterisation or overlapping them in some species as well as instability of morphological features, which often contribute to the potential misidentification (Ko et al. 2023). Since some of the Botryosphaeriaceae species do not produce anamorph and teleomorph structures on agar medium, species identification is difficult (Romero-Cuadrado et al. 2023a).

Challenges overcome with PCR-based molecular tools for diagnosing complex fungal species (Avenot et al. 2022; Romero-Cuadrado et al. 2023a). Significant advancements in molecular methods and associated phylogenetic analysis have had a profound impact on the systematics and taxonomy of significant plant pathogenic fungi including Botryosphaeriaceae family (Yang et al. 2017; Ko et al. 2023). Botryosphaeriaceae species could be accurately identified with sequencing of ITS region, EF1-α and β-tubulin gene (Holland et al. 2021; Özer et al. 2022; Ko et al. 2023). Consequently, the amplification of at least two or three of these genes for determination of nucleotide sequences can act as an effective diagnosis tool for identifying them using cultural and morphological characteristics (Goura et al. 2023; Romero-Cuadrado et al. 2023a).

In view of the above information, this study aimed to

I. diagnose the pathogens causing dieback, gummosis, trunk and branch cankers on almond trees in DSb type climates;
II. identify using molecular, cultural, and morphological characteristics of the pathogens, and
III. determine the virulence of pathogens through pathogenicity tests.

2. Material and Methods

2.1. Sampling and fungal isolation

Field studies were carried out in orchards established in DSb climates (Anonymous 2024) of Yozgat province, Türkiye in May 2022. The survey studies were conducted in seven almond orchards. The sampling was done randomly from ten trees each orchard, considering each tree as a replication taking 5 plant tissue samples from each replication exhibiting dieback, gummosis, trunk and branch cankers symptoms for further fungal isolation studies (Adesemoye et al. 2014). Fungal isolation from infected almond trees was performed according to the procedure described by Endes & Kayım (2022a). The isolates were purified using single spore technique following method procedure by Ko et al. (2023).

2.2. Morphological identification and characterization

The cultural (colony colour, aerial mycelium, mycelial growth rate, optimum temperature for growth) and conidial (conidial dimensions, shape, colour, the number of septum) characteristics of fungal isolates were determined comparatively with previous studies and fungal species were identified tentatively (Phillips et al. 2013).

The isolates were firstly grouped based on their cultural characteristics (Akgül et al. 2015; Endes & Kayım 2022a). Thereafter, to examine conidial morphology, cultures selected from the groups were incubated on Potato Dextrose Agar (PDA, Merck; 1.10130) and 3% Oat Meal Agar (OMA, 30 g oatmeal, 1000 mL distilled water) media at 25±1 °C for 4 weeks under fluorescent light at 12-hour intervals to promote sporulation (Adesemoye et al. 2014). The length and width of 50 conidia for each isolate were measured by light microscopy (Leica, DM 750) and the average and standard deviations were calculated. In addition, the structure, shape, colour and septa or without septa of the conidia were documented using a light microscope supplied with digital camera (Leica, DFC 450).

2.3. Effect of temperature on mycelial growth

Three isolates of each Botryosphaeriaceae species were used for this experiment. The 4 mm diameter agar discs obtained from 10-day-old cultures of Botryosphaeriaceae isolates were placed on PDA Petri dishes. Petri plates were incubated for 4 days at 5 °C intervals at 5 °C to 35 °C in the dark (Olmo et al. 2016). The colony diameter in each Petri plate was measured daily along two perpendicular axes (Goura et al. 2023). The experiment was designed according to the randomized complete block. Five replicates of each isolate (each replicate a petri dish) were used at each temperature. Moreover, the optimum temperature for radial growth and optimum daily radial mycelial growth (mm day^{-1}) of each isolate was calculated using third-order polynomial equations adapted using regression curves. Data were analysed using the Kruskal-Wallis test and the differences among the means were compared with Dunn's test at the 5% significance level (Endes 2021; Endes & Kayım 2022b).

2.4. Molecular identification and phylogenetic analyses

Total genomic DNA extraction, PCR analyses, and electrophoresis of Botryosphaeriaceae isolates were performed using protocol described by Olmo et al. (2016). To amplify ITS region of rDNA; a partial sequence of Beta-tubulin (β-tubulin) gene and a partial sequence of the elongation factor 1 alpha (TEF-1α), the primer ITS4/ITS5 (White et al. 1990); Bt2a/Bt2b (Glass & Donaldson 1995) and EF1-728F/EF1-986R (Carbone & Kohn 1999) were used, respectively. The resulting PCR products were sequenced by Molgentek Company (Adana, Türkiye). Sequences of Botryosphaeriaceae isolates were compared with NCBI

GenBank sequences of closely related species selected with the use of Blastn software. Consequently, all isolates were identified at the species level. In addition, the phylogenetic analyses [Maximum Parsimony (MP)] were performed using MEGA 11. Maximum parsimony for all analyses was performed using the heuristic search option (Branch Swapping NNI). Firstly, individual phylogenetic trees of three different gene regions of the isolates were constructed. Subsequently, three different gene regions were aligned since there was no sharp difference between the topologies of the trees. Bootstrap values were evaluated using 1000 replicates to test branch strength. *Guignardia philoprina* was used as an outgroup for phylogenetic analyses.

2.5. Pathogenicity tests

Pathogenicity experiments were carried out on two-year-old almond cv. Ferradual seedlings and 25 cm long cut the one-year-old healthy branch cuttings (cv: Ferradual) obtained from almond orchards. The detached branch pathogenicity tests were conducted as described by Endes et al. (2016). The cuttings were immersed in 1% sodium hypochlorite (NaOCl) for 10 min. Immediately, the cuttings were rinsed with tap water and bark tissue was removed from the middle of the cuttings with the help of a 4 mm diameter cork borer without damaging the xylem tissue. Seven-day-old PDA cultures were inserted into this aliquot with the same-sized cork borer. The inoculation area was wrapped with parafilm. All inoculated branch cuttings were placed in a transparent plastic container wiped with 96% ethanol and incubated for 15 days in the controlled room (25 °C temperature, 65% relative humidity, and 500 µmol m^{-2} s^{-1} photosynthetic active radiation). While the disease symptoms after inoculation were controlled routinely, the lengths of lesions formed in the xylem tissue of the branches were recorded after a 15-day incubation.

The second pathogenicity test, the most virulent isolates identified for each of the Botryosphaeriaceae species inoculated onto two-year-old almond seedlings under greenhouse conditions (Holland et al. 2021; Pouzoulet et al. 2022). Ten seedlings were used for each isolate. The inoculation was performed as described above. Disease symptoms were observed for three months' period, from July to September, and the length of xylem lesion in the tissue of the seedling stems was recorded.

2.6. Statistical analysis

Data obtained in the genetic study were analysed with Mega 11 software. All other data were analysed with SPSS v20 software. Prior to the statistical analyses, data of conidial dimensions, mycelial growth rates, and necrotic lesion lengths were checked for normality and homoscedasticity criteria. The dependent variables were analysed by one-way ANOVA. Posthoc test were performed using Tukey's Honestly Significant Difference test ($P<0.05$) to detect differences among the means.

3. Results and Discussion

3.1. Sampling and fungal isolation

Current study indicated that Botryosphaeriaceae species generally caused unilateral twig (Figure 1a) or entire canopy wilting in almond trees, subsequently leading to the drying of branches (Figure 1a) and trees (Figure 1b), especially towards the end of summer, before the falling of leaves from the trees. Gummosis and blight symptoms were observed on the trunks and main branches (Figure 1e-g) of the heavily infected trees (Figure 1c, d). Depending on the infection level, the colour of the bark tissue was darker (Figure 1h), and canker symptoms were clearly observed in the bark and woody tissues (Figure 1i, j) as well as gummosis in these areas. In addition, "V" shaped (Figure 1k-m) or similar necrotic lesions were observed on the xylem tissues when cross-sections were taken from the infected trunk and main branches.

Canopy wilting, dieback, gummosis, trunk and main branch cankers disease symptoms associated with Botryosphaeriaceae species on almond trees have been previously documented on almond trees in Spain (Olmo et al. 2016), Iran (Sohrabi et al. 2020), California (Holland et al. 2021), Türkiye (Özer et al. 2022) and Morocco (Goura et al. 2023). It was distinguished that the above mentioned disease symptoms associated with Botryosphaeriaceae cankers usually occurred on trunk cracks and near pruning wounds of 3-7 years old almond trees. These results were consistent with those obtained by Holland et al. (2021), who found the Botryosphaeriaceae species were associated with gummosis and V-shaped necrotic symptoms observed on 3-5 years old almond trees in California.

Figure 1- Disease symptoms caused by Botryosphaeriaceae species on almond trees in Yozgat, central Türkiye. a, b. Dieback and blight on the canopy; c, d. Gummosis (band canker) on the trunk; e – g. Gummosis in scaffold branch; h – j. Wood discoloration and band canker tissue on root collar; k – m. Wedge-shaped and irregular vascular discoloration in the wood of trunk or scaffold branch

Isolation studies showed that 5 out of 7 almond orchards were infected with Botryosphaeriaceae species. Based on the colony and conidial characteristics, 72 Botryosphaeriaceae isolates were grouped under four species. Incidence of *D. seriata* was noted on 34.7% of all isolates, followed by *N. parvum* (31.9%), *Botryosphaeria dothidea* (18.1%), and *L. theobromae* (15.3%).

In the present study, symptoms associated with Botryosphaeriaceae pathogens were observed mostly on 3 to 7 years old almond trees. Botryosphaeriaceae symptoms were found in 71.4% of the total almond orchards. In contrast, Moral et al. (2019) reported that 40% of almond orchards including 10-80 years old almond trees on the island of Mallorca had disease symptoms related to Botryosphaeriaceae pathogens. The significant difference between these two studies can be explained by different tree ages in the almond orchards. In addition, Michalides et al. (2018) reported that young almond trees were more exposed to attack by Botryosphaeriaceae pathogens than older almond trees. Moreover, in this study, *D. seriata* was determined as the dominant species in agreement with those of Olmo et al. (2016) reporting that *L. theobromae* was the least prevalent species isolated. This can be explained that *D. seriata* causes natural infection more commonly than *L. theobromae* (Romero-Cuadrado et al. 2023b).

3.2. Molecular identification and phylogenetic analyses of Botryosphaeriaceae species

Considering the cultural and conidial characteristics of isolates, 16 out of 72 Botryosphaeriaceae isolates were sequenced for phylogenetic analysis. The ITS, β-tubulin, and TEF-1α gene sequences of these isolates were deposited in NCBI GenBank database with accession numbers (Table 1).

The sequence length of 16 isolates ranged 542 to 583 bp for ITS, 427 to 449 bp for β-tubulin, and 282 to 309 bp for TEF-1α. Phylogenetic trees of ITS, β-tubulin and TEF-1α (28 taxa, 331 characters) gene regions were constructed according to the maximum parsimony of each dataset. The combined ITS, β-tubulin, and TEF1-α dataset of Botryosphaeriaceae spp. contained 28 taxa and 1522 characters (including alignment gaps).

Table 1- Isolates sequenced in this study and from GenBank included in the phylogenetic analyses

Species	*Isolates*[a]	*GenBank accession number*[b]		
		ITS	*TUB2*	*TEF1*
Diplodia seriata	YBUPd1	OP419496	OP819565	OQ053499
D. seriata	YBUPd2	OP419497	OP973766	OQ053500
D. seriata	YBUPd3	OP419498	OP973767	OQ053501
D. seriata	YBUPd4	OP419499	OP973768	OQ053502
D. seriata	YBUPd5	OP419500	OP973769	OQ053503
D. seriata	**CBS 112555^{T}**	AY259094	DQ458856	AY573220
D. seriata	**PUCV2090**	MT023558	MT063125	MT120819
D. seriata	**GA-422**	HQ660463	HQ660477	HQ660489
Neofusicoccum parvum	YBUPd6	OP419501	OP973770	OQ053504
N. parvum	YBUPd7	OP419502	OP973771	OQ053505
N. parvum	YBUPd8	OP419503	OP973772	OQ053506
N. parvum	YBUPd9	OP419504	OP973773	OQ053507
N. parvum	YBUPd10	OP419505	OP973774	OQ053508
N. parvum	**CMW9081^{T}**	AY236943	AY236917	AY236888
N. parvum	**CBS 145623**	MN611180	MN623344	MN623347
N. parvum	**MBAi51AG**	KJ921840	KP721702	KP721664
Botryosphaeria dothidea	YBUPd11	OP419506	OP973775	OQ053509
B. dothidea	YBUPd12	OP419507	OP973776	OQ053510
B. dothidea	YBUPd13	OP419508	OP973777	OQ053511
B. dothidea	**CMW8000^{T}**	AY236949	AY236927	AY236898
B. dothidea	**KARE1300**	MN166016	MN318117	MN318089
Lasiodiplodia theobromae	YBUPd14	OP419509	OP973778	OQ053512
L. theobromae	YBUPd15	OP419510	OP973779	OQ053513
L. theobromae	YBUPd16	OP419511	OP973780	OQ053514
L. theobromae	**CBS 164.96^{T}**	AY640255	EU673110	AY640258
L. theobromae	**UCD191Co**	DQ008308	DQ008331	EU012397
L. theobromae	**MBAI28AG**	KF182331	KP721698	KP721660
Guignardia philoprina*	**CBS447.68**	FJ824768	FJ824779	FJ824773

[a] = Isolates of species in bold were generated from GenBank. T = Isolates are ex-type specimens. [b] = Sequences were registered in the gene bank according to three different gene regions. ITS = Internal Transcribed Spacer, TUB2 = β-tubulin-2, TEF1 = Translation Elongation Factor 1-α gene regions. Asterisk (*) represented the out-group

The combined data consisted of 281 informative characters for parsimony. Using data in current study, one of the trees showed the most parsimony. As a result of maximum parsimony analysis, the tree length, consistency index, retention index, and composite index were identified as 350, 0.911, 0.973, and 0.887, respectively (Figure 2). Composite data of the most parsimonious tree analysis, without rooting, resulted in clustering of Botryosphaeriaceae isolates into two major clades. Each of the main clades were further subdivided into two sub-clades resulting in total of four distinct clusters in Botryosphaeriaceae isolates previously identified in the phylogenetic tree. The first major clade, *D. seriata* (YBUPd1, YBUPd2, YBUPd3, YBUPd4, YBUPd5) clustered with *L. theobromae* (YBUPd14, YBUPd15, YBUPd16); and the second major clade *N. parvum* (YBUPd6, YBUPd7, YBUPd8 YBUPd9, YBUPd10) clustered with *B. dothidea* (YBUPd11, YBUPd12, YBUPd13).

D. seriata has been reported as a pathogen of almond trees in many different countries (Olmo et al. 2016; Holland et al. 2021; Jiménez Luna et al. 2022). Moreover, *D. seriata* has also been recorded as aggressive pathogen from almond, plum, nectarine, and walnut by Kayım et al. (2015), Endes et al. (2016), Endes & Kayım (2022a) and Çiftçi et al. (2023) with the same sequence.

N. parvum was the most frequently isolated second species in this study and it has been previously reported to cause the largest cankers on trunks and limbs of almond trees in Iran (Sohrabi et al. 2020) and California (Jiménez Luna et al. 2022). This species was identified as a pathogen on almond trees by Kayım et al. (2015) along with identification of *N. parvum* as highly aggressive pathogen of other woody plant species like vineyard (Akgül et al. 2015) and plum (Endes & Kayım 2022a).

The other species, *B. dothidea* was also isolated from cankered tissues of almond trees in California (Michalides et al. 2018). However, there is no report showing that *B. dothidea* caused infection on almond trees in Türkiye. Therefore, it is assumed as first report on the subject.

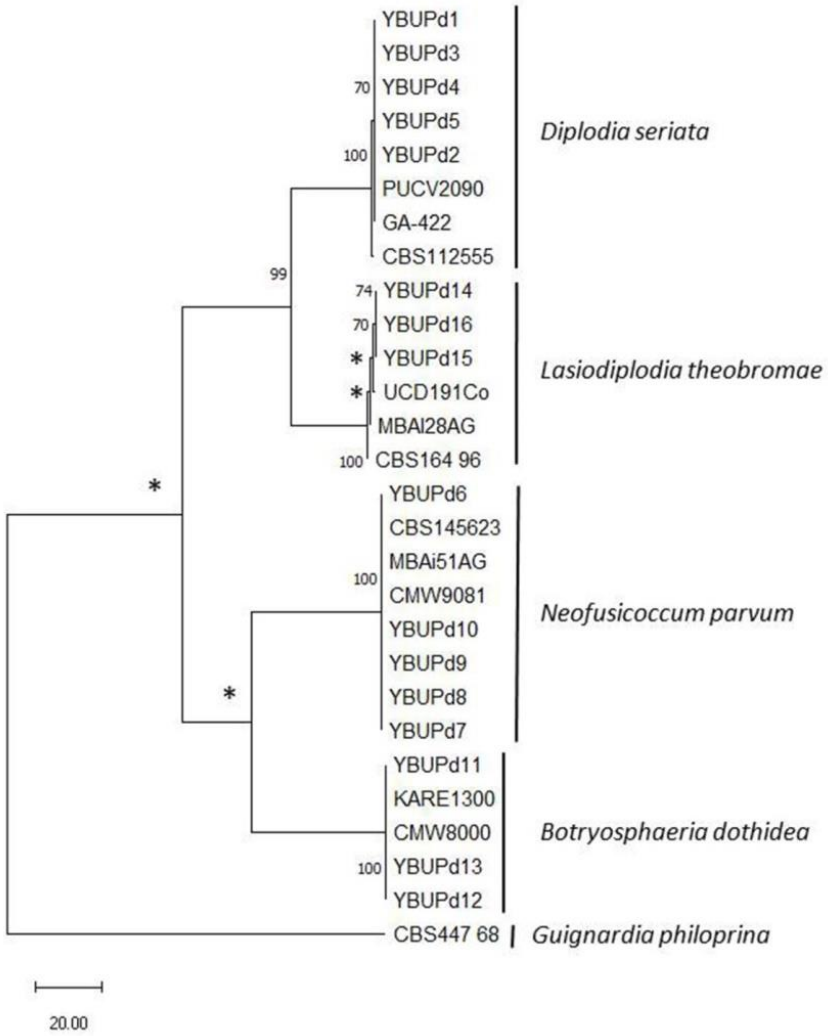

Figure 2- Most parsimonious unrooted tree based on internal transcribed spacer (ITS)1, 5.8S ribosomal DNA, ITS2, partial β-tubulin gene, and elongation factor 1-α sequences of Botryosphaeriaceae species inferred from maximum parsimony analysis using MEGA 11. Numbers on branches are bootstrap values >70% in 1,000 replicates. Bootstrap values <70% are indicated asterisk. Isolate CBS447 68 (*Guignardia philoprina*) was added as an outgroup. CBS = Centraalbureau Schimmelcultures, Utrecht, The Netherlands; CMW = Culture Collection Forestry and Agricultural Biotechnology Institute, University of Pretoria, South Africa; UCD = University of California, Davis; UCR = University of California, Riverside; KARE = Kearney Agricultural Research and Extension; MBA = Türkiye isolates; GA-422 = Chinese isolate; PUCV2090 = Chile isolate. The other isolates were sequenced in this study

The last species, *L. theobromae* is a well-known as a serious pathogen that effects almond trees in agreement with the literature (Sohrabi et al. 2020; Goura et al.2023) and can cause a variety of disease symptoms, (Inderbitzin et al. 2010). The disease is frequently on fruit species like figs (Çeliker & Michailides 2012), strawberries (Yildiz et al. 2014), vineyards (Akgül et al. 2015), nectarine (Endes et al. 2016) and almond (Özer et al. 2022).

3.3. Morphological identification of Botryosphaeriaceae species

Botryosphaeriaceae isolates were used to characterize culture and conidia (Table 2, 3). All isolates produced anamorphic structures within 3 to 4 weeks on PDA, 3% OMA and autoclaved 20 mm long almond shoots on the ½PDA medium. No ascospores were observed on different media. Morphological characterization studies, showed no overlap between the characters such as colour, septate, conidial dimensions as well as the colony development of the species. The isolates could be separated into four species based on the characteristics of colony growth and conidial morphology (Figure 3).

The first group, *Diplodia* spp. had aerial and fast-growing mycelium (Table 3), which were initially whitish-grey, later turned dark olive-grey with age. Small pycnidia of the isolates formed on PDA medium, 3% OMA, and almond shoots. Conidia were initially colourless and aseptate, turning to dark brown over time, some rarely with one septate. Conidia were oval, ellipsoid, or

cylindrical, broad at the tip, rounded, and truncated at the base. The sizes of the conidia are given in Table 2. This was identified as *D. seriata*. This pathogenic species was occasionally isolated from almond trees showing symptoms of dieback, gummosis and trunk cankers (Holland et al. 2021; Jiménez Luna et al. 2022). The findings of cultural and conidial characteristics in this study were in agreement with findings of Olmo et al. (2016) who identified *D. seriata* as the based on morphological characteristics on almond trees in Spain. Akgül et al. (2015) reporting that *D. seriata* isolates easily formed the colony with olive-grey colour on PDA medium and produced the conidia with one septate.

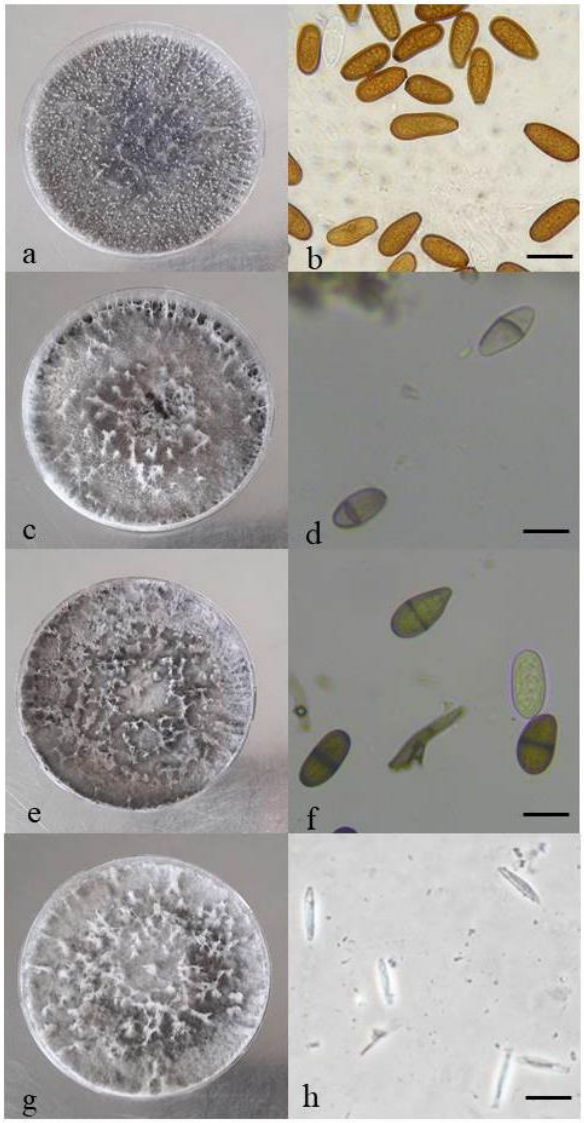

Figure 3- a–b, *Diplodia seriata*; c–d, *Neofusicoccum parvum*; e–f, *Lasiodiplodia theobromae* and g–h, *Botryosphaeria dothidea* (anamorph: *Fusicoccum aesculi*). conidial morphology. a, Colony morphology of 10-day-old *D. seriata*. b, mature brown conidia. c, Colony morphology of 10-day-old *N. parvum*. d, Pale-brown mature conidia. Central septum can be observed. e, Colony morphology of 10-day-old *L. theobromae*. f, Young colourless and mature brown conidia. g, Colony morphology of 10-day-old *B. dothidea*. h, Colourless and thin-walled conidia. Scale bars = 10 µm

The other fungal species produced fast-growing and fluffy mycelium (Table 3). The colonies were initially white, later turned pastel grey with age. None of the isolates produced pycnidia on PDA and 3% OMA agar. However, quite a few pycnidia were observed on almond shoots. The conidia were fusiform or ellipsoidal, colourless, and non-septate, while mature conidia were light brown, and usually contained one or two septate with age. Conidia dimensions are given in Table 2. This species was identified as *N. parvum*.

Table 2- Conidial size of Botryosphaeriaceae species obtained from current and previous studies

Species	*Isolate*[a]	*Conidial size (µm) (L × W)*[b]	*Mean ± SD (µm) (L × W)*[c]	*L/W ration*[d]	*Source of data*
Diplodia seriata	YBUPd1	(17.5–)19.9–23.7(–27.0) × (8.5–)9.6–11.0(–11.8)	21.8 ± 1.9 × 10.3 ± 0.7	2.1	This study
D. seriata	YBUPd3	(18.8–)20.9–24.4(–25.0) × (8.8–)10.0–11.4(–11.8)	22.7 ± 1.8 × 10.7 ± 0.7	2.1	This study
D. seriata	YBUPd5	(18.8–)19.8–22.9(–25.0) × (9.5–)10.0–11.3(–12.0)	21.4 ± 1.5 × 10.7 ± 0.7	2.0	This study
D. seriata	**CBS 112555^{T}**	**(21.5–)22–27(–28) × (11–)11.5–14.5(–15.5)**	**24.9 ± 1.9 × 12.9 ± 1.1**	**1.9**	**Phillips et al. 2007**
D. seriata	**BAL-10**	**(19.5–)20–26,5(–27) × (10.5–)11.5–14(–15)**	**23.6 ± 1.4 × 11.9 ± 0.8**	**2.0**	**Olmo et al. 2016**
Neofusicoccum parvum	YBUPd7	(11.3–)15.3–20.6(–23.8) × (3.8–) 5.1–6.7(–8.0)	17.9 ± 2.6 × 5.9 ± 0.8	3.0	This study
N. parvum	YBUPd8	(14.8–)16.6–20.7(–23.8) × (4.5–) 5.3–6.7(–8.0)	18.7 ± 2.0 × 6.0 ± 0.7	3.1	This study
N. parvum	YBUPd10	(12.5–)15.0–21.1(–28.3) × (3.8–) 4.7–6.7(–7.5)	18.0 ± 3.1 × 5.7 ± 1.0	3.2	This study
N. parvum	**CMW9081^{T}**	**(12–)15–19(–24) × 4–6**	**16.9 × 5.4**	**3.1**	**Slippers et al. 2004**
N. parvum	**BAL-42**	**(13.5–)16–20(–22.5) × (4.5–)5.5–6(–6.5)**	**17.9 ± 1.3 × 5.6 ± 0.7**	**3.2**	**Olmo et al. 2016**
Botryosphaeria dothidea	YBUPd11	(23.8–)25.0–27.6(–28.5)× (4.0–)4.6–5.7(–6.8)	26.3 ± 1.3 × 5.2 ± 0.6	5.1	This study
B. dothidea	YBUPd12	(24.0–)25.2–27.8(–28.8)× (4.5–)4.8–5.9(–6.8)	26.5 ± 1.3 × 5.4 ± 0.5	5.0	This study
B. dothidea	YBUPd13	(24.0–)25.2–27.5(–28.5)× (4.5–)4.8–5.6(–6.0)	26.3 ± 1.2 × 5.2 ± 0.4	5.1	This study
B. dothidea	**CMW8000^{T}**	**(20–)23–27(–30)× 4–5(–6)**	**24.7 × 4.9**	**5**	**Slippers et al. 2004**
B. dothidea	**2E55**	**(22.5–)24–28.5(–32)× (4.5–)4.5–6.5(–7.5)**	**26.4 ± 2.4 × 5.5 ± 0.8**	**4.8**	**Chen et al. 2014**
Lasiodiplodia theobromae	YBUPd14	(21.3–)23.9–28.4(–31.3) × (11.3–)12.6–15.1(–16.3)	26.2 ± 2.3 × 13.8 ± 1.3	1.9	This study
L. theobromae	YBUPd15	(22.5–)24.7–28.1(–30.0) × (12.5–)13.3–15.3(–16.3)	26.4 ± 1.7 × 14.3 ± 1.0	1.9	This study
L. theobromae	YBUPd16	(19.3–)22.2–27.3(–29.3) × (10.8–)12.5–15.2(–16.3)	24.8 ± 2.6 × 13.8 ± 1.3	1.8	This study
L. theobromae	**CBS 164.96^{T}**	**(19–)21–31(–32.5) × (12–)13–15.5(–18.5)**	**26.2 ± 2.6 × 14.2 ± 1.2**	**1.9**	**Alves et al. 2008**
L. theobromae	**7E87**	**(17.5–)20–24(–28) × (9–)11.5–13(–15.5)**	**22.0 ± 1.9 × 12.5 ± 0.4**	**1.8**	**Chen et al. 2014**

[a]: Isolates of species in bold were generated from previous studies. T = isolates are ex-type or from samples that have been linked morphologically to type material of the species. [b] L × W = length by width; (minimum–) average ± SD [Standard Deviation] (–maximum). [c] L × W = length by width. [d] L/W = average length/average width

Similar to the current findings associated with the cultural and morphological characterisation of *N. parvum* isolates, Phillips et al. (2013) who described the diagnostic key of Botryosphaeriaceae species, that indicated their conidia, which become mature over time, are light brown in colour and have one or two septate. Paradoxically, *N. parvum* isolates cannot produce either young (Amponsah et al. 2008) or mature (Adesemoye et al. 2014) conidia on synthetic agar medium. This and previous study confirm that the production of conidia of Botryosphaeriaceae species is stimulated by the host plant tissues from which they are isolated. The third fungus species had very similar colony characteristics and showed similarities to the reported second fungus isolates which did not produce pycnidia on PDA and 3% OMA agar but produced very few pycnidia on almond shoots. These colonies spread outward from the centre of the Petri dish in olive-grey colour. Conidia were fusiform, ellipsoid, non-septate, and colourless. The sizes of the conidia are given in Table 2. This fungus was identified as *B. dothidea*. Zhang et al. (2013) reported that the conidia of *B. dothidea* were colorless, aseptate, thick-walled and fusoid-shaped, and their average conidia size was 20.5 × 5.5 (n = 50). This and previous studies, showed that *B. dothidea* appears to have longer conidia (Table 2). On the other hand, the findings were inagreement with those of Türkölmez et al. (2016), who reported that apple isolates of *B. dothidea* initially formed grey, but black colonies over time.

The fourth fungus colonies initially formed white and fluffy mycelium but became dark olive green, and lastly black with age. They produced larger and more abundant pycnidia onto the PDA, 3% OMA and on almond shoots compared to other fungus species. The conidia were oval, ellipsoid, thick-walled, colourless, and non-septate, while the conidia were dark brown as they matured. Conidia were one-septate with a longitudinally straight appearance. The sizes of the conidia are given in Table 2. This group was identified as *L. theobromae*. The findings of the cultural and morphological characteristics of this fungus are associated with *L. theobromae* in agreement with those by Goura et al. (2023), who reported that *L. theobromae* have aerial mycelium, white grey at the surface, olivaceous grey at the reverse plate, and became dark grey after two weeks of incubation on almond.

Table 3- Temperature–growth relationship for Botryosphaeriaceae isolates*

Species	*Isolate*	*Adjusted model*[a]					*Temperature (°C)*[b]	*Growth (mm day^{-1})*[c]
		R^2	*a*	*b*	*c*	*d*		
Diplodia seriata	YBUPd1	0.987	-0.004	0.175	-1.018	0.666	26.4 b	23.9 b
D. seriata	YBUPd3	0.980	-0.004	0.178	-1.048	0.669	26.5 b	23.5 b
D. seriata	YBUPd5	0.985	-0.004	0.189	-1.226	1.503	26.4 b	23.5 b
Neofusicoccum parvum	YBUPd7	0.978	-0.004	0.170	-0.932	0.120	25.3 c	20.4 b
N. parvum	YBUPd8	0.981	-0.004	0.176	-1.042	0.583	26.1 bc	22.2 b
N. parvum	YBUPd10	0.980	-0.004	0.175	-1.040	0.569	26.0 bc	21.8 b
Botryosphaeria dothidea	YBUPd11	0.963	-0.004	0.208	-1.825	3.869	29.6 a	28.1 a
B. dothidea	YBUPd12	0.955	-0.004	0.213	-1.913	4.194	29.9 a	28.9 a
B. dothidea	YBUPd13	0.953	-0.004	0.210	-1.882	4.100	29.9 a	28.9 a
Lasiodiplodia theobromae	YBUPd14	0.946	-0.004	0.194	-1.593	2.623	27.7 b	22.5 b
L. theobromae	YBUPd15	0.939	-0.004	0.189	-1.518	2.317	26.9 b	20.6 b
L. theobromae	YBUPd16	0.939	-0.004	0.189	-1.519	2.329	26.9 b	20.4 b

*: Data are the average of five replicates for each isolate. For each column, means with the same letter are not significantly different according to Kruskal-Wallis all pairwise comparisons test (p = 0.05). [a] Mycelial growth on potato dextrose agar at 5 to 35°C was adjusted to a third-degree polynomial model: $Y = aT^3 + bT^2 + cT + d$ in which Y = mycelial growth (mm/day); a, b, c and d are the regression coefficients; and R^2 = coefficient of determination. [b] Optimal temperature estimated by the adjusted model. [c] Maximum growth rate estimated by the adjusted model

The results of morphological studies of *L. theobromae* resemble with those mentioned by Endes et al. (2016), who firstly found *L. theobromae* as an aggressive pathogen on nectarine trees in Türkiye. The same authors reported that the conidia of *L. theobromae* were initially colourless, aseptate, ellipsoid or round, but with age they turned brown, one septate and longitudinally striped appearance.

Overall, the cultural and micro morphological characters as well as the PCR-based sequence information revealed that fungi of Botryosphaeriaceae species are generally associated with anamorphic genera like *Fusicoccum* and *Diplodia* (Phillips et al. 2013). Studies proved significant differences between the morphological characters of these two genera of Botryosphaeriaceae (Wang et al. 2011). Slippers & Wingfield (2007) reported that *Fusicoccum*-like species form hyaline (colorless), narrow (< 10 µm) conidia and have thin conidia walls (< 0.5 µm); *Diplodia*-like species, on the other hand, have wider conidia (>10 µm) and thicker conidia walls (0.5 – 2 µm), with colored conidia over time in mature format maturity. The other important anamorphic genus of Botryosphaeriaceae fungi, *Lasiodiplodia*, have always been simple grouped separately from these two genera because it contains longitudinal stripes on its conidia (Endes & Kayım 2022a; Özer et al. 2022; Goura et al. 2023).

3.4. Effect of temperature on mycelial growth

None of the isolates studied grew on PDA culture at 5 °C. *L. theobromae* isolates showed no mycelial growth at 10 °C, while the other isolates showed highly limited growth at same temperature. *L. theobromae* isolates had an average growth rate of 11.7 mm day^{-1} at 35 °C, while other isolates showed limited growth. The optimum temperature for mycelial growth was in the range of 25.3 - 29.9 °C (Table 3). Significant differences were found in the optimum growth temperature of the isolates ($P<0.05$). The maximum temperatures for growth were 26 °C, 26 °C, 27 °C, and 29 °C for *D. seriata*, *N. parvum*, *L. theobromae* and *B. dothidea* isolates respectively (Table 3).

The Kruskal-Wallis test also showed that the maximum growth rates of the isolates changed significantly ($P<0.05$). For all isolates, the relationship between growth rate and temperature was best described by a third-order polynomial ($Y = aT^3 + bT^2 + cT + d$). In any case, the three regression coefficients were highly significant ($P<0.05$), and the coefficient of determination (R^2) ranged from 0.939 to 0.987 (Table 3). The isolates were statistically categorized into two groups. The first group consisted of *B. dothidea* isolates with a maximum growth rate of >28 mm day^{-1}, while the second group included rest of the isolates with a maximum growth rate of <28 mm day^{-1} (Table 3).

Ismail et al. (2013) showed that *Neofusicoccum* species (*N. parvum* and *N. australe*) developed at minimum temperature of 10 °C, optimum temperature of 25 °C, and maximum temperature of 35 °C. Also, Thomidis et al. (2011) has also mentioned that the optimum temperature for radial mycelial growing of *N. parvum* was the 25 °C. The findings of present study were in concordance with data of studies mentioned above.

Copes & Hendrix (2004) reported that *B. obtusa* (anamorph, *D. seriata*) can grow from 8 °C to 36 °C, but the optimum temperature for growth is between 20 °C and 26 °C, and mycelial growth did not observed at 4 °C. Furthermore, the same

researchers found that *L. theobromae* developed from 15 °C to 35 °C, with an optimum mycelial temperature for growth between 25 °C and 35 °C. Similarly, Wang et al. (2011) found that *L. theobromae* showed a faster mycelial growth percentage at 25 °C than *D. seriata*; Chen et al. (2014) found that *N. parvum*, *D. seriata* and *L. theobromae* exhibited optimum mycelial growth at 25 and 30 °C, respectively. In addition, *B. dothidea* showed the higher maximum temperature for optimum mycelial growth compared to the other three species. Similarly, the optimum temperature range for mycelial growth of *B. dothidea* was determined in the range of 25 °C to 32 °C (Luo et al. 2022). Moreover, Zhang et al. (2013) reported that the optimum temperature for radial mycelial development of *B. dothidea* was 30 °C, followed by 25 °C, 20 °C and 35 °C.

3.5. Pathogenicity test

All Botryosphaeriaceae isolates were re-isolated from inoculated almond branches at rates ranging from 80 to 100% after a 15-day incubation. No symptoms were observed in the wood tissue of the branches used as control, and no pathogen was isolated (Table 4). *L. theobromae* and *N. parvum* isolates caused more gummosis in the inoculation sites compared to *D. seriata* and *B. dothidea* isolates. The mean of lesion lengths formed in wood tissue by all Botryosphaeriaceae isolates was significantly ($P<0.05$) different compared to the control (Table 4). All *N. parvum* isolates were statistically grouped into the same class and had significantly ($P<0.05$) different mean necrosis lengths, which were longer than other lesions by other isolates. However, *D. seriata* isolates differed significantly ($P<0.05$) among themselves and the control treatment.

D. seriata isolates were grouped into two classes based on virulence levels (Table 4). *L. theobromae* was the second species having the most virulent isolates with the most significant amount of gummosis formation in the inoculation sites (Li et al. 2014). *B. dothidea* isolates were statistically grouped into a single class. *B. dothidea* isolates showed higher virulence levels than *D. seriata* isolates while they have lower virulence levels than *N. parvum* and *L. theobromae* isolates.

Table 4- Average wood discoloration length on detached branches of *Prunus dulcis* cv. Ferradual, caused by mycelium plug inoculations of Botryosphaeriaceae species

Species[a]	Isolate	Average wood discoloration length (mm)[b] ± SE		Gummosis[c]	Reisolation[d]
Diplodia seriata	YBUPd1	39.5 ± 0.6	de	+	10
	YBUPd2	37.3 ± 1.1	e	n/a	9
	YBUPd3	40.8 ± 1.3	de	++	10
	YBUPd4	37.1 ± 1.1	e	n/a	10
	YBUPd5	42.2 ± 1.2	d	+	8
Neofusicoccum parvum	YBUPd6	98.8 ± 1.1	a	++	10
	YBUPd7	97.9 ± 0.8	a	+	10
	YBUPd8	99.5 ± 0.9	a	+++	9
	YBUPd9	98.6 ± 0.8	a	+++	9
	YBUPd10	98.9 ± 0.9	a	++	10
Botryosphaeria dothidea	YBUPd11	54.6 ± 1.0	c	+	8
	YBUPd12	53.6 ± 1.0	c	++	9
	YBUPd13	54.9 ± 0.6	c	+	9
Lasiodiplodia theobromae	YBUPd14	68.9 ± 0.7	b	+++	10
	YBUPd15	70.4 ± 0.9	b	++++	10
	YBUPd16	68.6 ± 1.0	b	+++	10
Control	—	6.4 ± 0.3	f	n/a	0

[a] Botryosphaeriaceae isolates were identified by morphological and molecular analyses. [b] Values followed by the same letters are not significantly different at $P<0.05$ according to Tukey's HSD test ($P<0.05$). [c] n/a = not available, + = Poor, ++ = Moderate, +++ = Profuse, ++++ = Abundant. [d] Number of the samples from which the fungus was reisolated out of 10 inoculated samples each.

The statistically highly aggressive isolates, as determined by branch pathogenicity results were selected for pathogenicity studies of seedlings, one isolate representative of each species (Figure 4). Similar results were obtained with branch cuttings pathogenicity tests after a 90-day incubation. Gum exudates were observed at the inoculation points 2-3 weeks after Botryosphaeriaceae isolates were inoculated to the stems of two-year-old almond seedlings. The average lengths of woody discoloration caused by Botryosphaeriaceae species were shown in Figure 4.

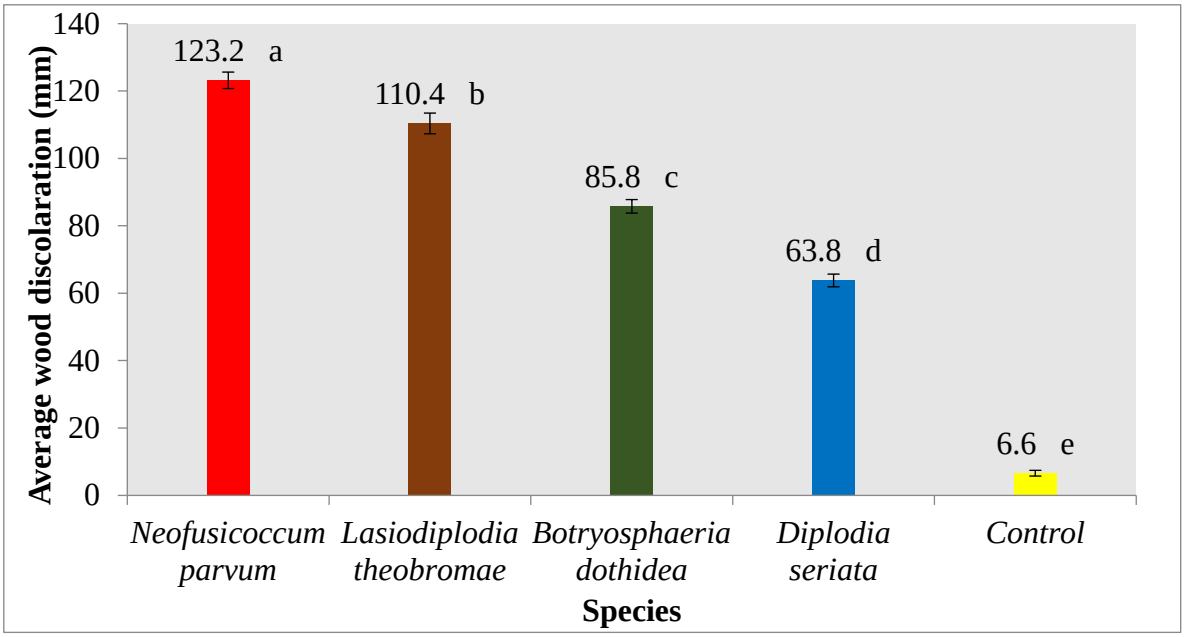

Figure 4- Average wood discoloration length (mm) on 2-years-old almond seedlings cv. Ferradual after a 90-day incubation with a mycelium plugs of four Botryosphaeriaceae species (*N. parvum* = YBUPd10; *B. dothidea* = YBUPd13; *L. theobromae* = YBUPd14; *D. seriata* = YBUPd5). Bars topped with different letters indicate treatment means that are significantly different (P<0.05) using the Tukey's HSD test. Vertical lines represent the standard errors of the means

All species differed significantly (P<0.05) among them in the length of lesions formed in the wood tissue of the trunk in almond seedlings (Figure 4). *N. parvum* was the most virulent strain and had a mean lesion length (123.2 mm) that was significantly (P<0.05) longer than the other strains, followed by *L. theobromae*, *B. dothidea*, and *D. seriata* (Figure 4). Pathogenicity test results showed that *L. theobromae* and *N. parvum* caused more gum formation on seedling stems. All pathogenic Botryosphaeriaceae species were successfully (100%) re-isolated from the stems of almond seedlings, thus confirming Koch's postulates. No pathogenic fungal organisms were isolated from control seedlings.

Pathogenicity tests (Table 4; Figure 4) determined *D. seriata*, *N. parvum*, *B. dothidea* and *L. theobromae* as pathogens in almond trees in Spain (Olmo et al. 2016) California (Holland et al. 2021) and Morocco (Goura et al. 2023). The results of one-year-old branch cuttings and seedlings pathogenicity overlap entirely with each other. On branch cuttings with various isolates, lesions ranged in length from 37.1 mm to 99.5 mm on average, whereas no lesions were produced on control cuttings treated with PDA plugs devoid of mycelial fungi (controls).

In the second pathogenicity test, the isolates formed longer lesions on the trunks of almond seedlings. Pathogenicity tests also demonstrated that *N. parvum* exhibited the highest virulence on both branch cuttings and seedlings, resulting in longer lesions that averaged 98.7 mm and 123.2 mm, respectively. These results are consistent with findings of Inderbitzin et al. (2010), demonstrating that *N. parvum* and *N. nonquaesitum* species were found to be the most virulent when tested for virulence on almonds in California. In another study, Olmo et al (2016) reported that *Neofusicoccum* species were generally the most virulent in the almond cultivars tested, although there were differences between years in the pathogenicity test.

Furthermore, the pathogenicity tests revealed that the *L. theobromae* was determined to the second most virulent species on almond seedlings causing a longer lesion of an average of 110.4 mm. Özer et al. (2022) reported that *L. theobromae* was carried out the necrotic lesions with an average length of 60 to 80 mm on wood tissues of one-year-old almond seedlings were observed within 4 weeks in Türkiye. This result contrasts with that reported by Goura et al. (2023), who determined that *L. theobromae* was the most virulent strain, resulting in the longest necrotic lesion (285.17 mm) on almond twigs in Morroco. This difference can be explained by the different resistance mechanisms of host plant against each isolate in species with a wide host range such as *L. theobromae* (549 hosts), *B. dothidea* (514 hosts), *N. parvum* (295 hosts) and *D. seriata* (264 hosts) (Olmo et al. 2016; Silva-Valderrama et al. 2024).

In addition, *B. dothidea* produced less gum and lesions in trunk tissue than compared to the *N. parvum* and *L. theobromae*. Hovewer, *B. dothidea* species of the Botryosphaeriaceae is well known as a serious pathogen of almond trees globally (Olmo et al. 2016; Moral et al. 2019), and it is the Botryosphaeriaceae species most isolated from trunk and limb cankers on almond trees in California (Michailides et al. 2017).

In the present study, the different virulence levels were observed in artificial inoculation studies on almond seedlings and branch cuttings with *D. seriata* isolates. These results were similar to the pathogenicity test results of Inderbitzin et al. (2010) on

almond cultivars in California. Additionally, the pathogenic status of *D. seriata* in other hosts such as grapevine (Akgül et al. 2015) and plum (Endes & Kayım 2022a) is not very clear and still controversial among researchers. The findings in this study showed that *D. seriata* is a pathogenic species on almonds in Yozgat province, and *D. seriata* is one of the most isolated species of Botryosphaeriaceae family. Indeed, this pathogen is known to cause disease in a wide range of hosts (Olmo et al. 2016).

4. Conclusions

Current study provides the development of effective management strategies for these four species causing dieback, gummosis and trunk and limb cankers on woody plants. Because these species are among the potential risk factors for citrus, vineyard, pome, stone and nuts trees in the different region, which is one of the most important fruit production centres of Türkiye. Therefore, to avoid or prevent diseases caused by *Botryosphaeria*ceae species on almonds and other host plants, good care of fruit trees as well as the application of protective fungicide, especially after pruning, can be a good prevention approach.

References

Adesemoye A O, Mayorquin J S, Wang D H, Twizeyimana M, Lynch S C & Eskalen A (2014). Identification of species of Botryosphaeriaceae causing bot gummosis in Citrus in California. *Plant Disease* 98(1): 55-61. https:// doi.org/10.1094/ PDIS-05-13-0492-RE

Akgül D S, Savaş N G, Teker T, Keykubat B, Mayorquin J S & Eskalen A (2015). Fungal trunk pathogens of Sultana Seedless vineyards in Aegean region of Türkiye. *Phytopathologia Mediterranea* 54(2): 380-393. https://doi.org/ 10.14601/Phytopathol_Mediterr-16138

Alves A, Crous P W, Correia A & Phillips A J L (2008). Morphological and molecular data reveal cryptic speciation in *Lasiodiplodia theobromae*. *Fungal diversity* 28: 1-13

Amponsah N T, Jones E E, Ridgway H J & Jaspers M V (2008). Production of *Botryosphaeria* species conidia using grapevine green shoots. *New Zealand Plant Protection* 61: 301-305. https://doi.org/10.30843/nzpp.2008.61.6840

Anonymous (2024). Köppen geiger system. https://tr.climate-data.org/asya/tuerkiye/yozgat-630/ (accessed on 07.02.2024)

Antón-Domínguez B I, López-Moral A, Raya M C, Lovera M, Melgar S, Roca L F, Arquero O, Trapero A & Agustí-Brisach C (2023). Fungal Pathogens Associated with Almond Decline Syndrome, an Emerging Disease Complex in Intensive Almond Crops in Southern Spain. *Plant Disease* 107(12): 3737-3753. https://doi.org/10.1094/PDIS-04-23-0759-RE

Avenot H F, Jaime-Frias R, Travadon R, Holland L A, Lawrence D P & Trouillas F P (2022). Development of pcr-based assays for rapid and reliable detection and identification of canker-causing pathogens from symptomatic almond trees. *Phytopathology* 112(8): 1710-1722. https://doi.org/10.1094/PHYTO-08-21-0351-R

Carbone I & Kohn L M (1999). A method for designing primer sets for speciation studies in filamentous ascomycetes. *Mycologia* 91(3): 553-556. https://doi.org/10.1080/00275514.1999.12061051

Çeliker N M & Michailides T J (2012). First report of *Lasiodiplodia theobromae* causing canker and shoot blight of fig in Türkiye. *New Disease Reports* 25(12): 2044-0588

Chen S, Morgan D P, Hasey J K, Anderson K & Michailides T J (2014). Phylogeny, morphology, distribution, and pathogenicity of Botryosphaeriaceae and Diaporthaceae from English walnut in California. *Plant Disease* 98(5): 636-652. https://doi.org/10.1094/PDIS-07-13-0706-RE

Çiftçi O, Özer G, Türkölmez Ş. & Derviş S (2023). *Lasiodiplodia theobromae* and *Neoscytalidium dimidiatum* associated with grafted walnut (*Juglans regia* L.) decline in Turkey. *Journal of Plant Diseases and Protection* 130: 1117–1128. https://doi.org/10.1007/s41348-023-00745-5

Copes W E & Hendrix Jr F F (2004). Effect of temperature on sporulation of *Botryosphaeria dothidea*, *B. obtusa*, and *B. rhodina*. *Plant Disease* 88(3): 292-296. https://doi.org/10.1094/PDIS.2004.88.3.292

EFSA Panel on Plant Health (PLH), Bragard C, Baptista P, Chatzivassiliou E, Gonthier P, Jaques Miret J A, ... & Yuen J (2023). Commodity risk assessment of *Prunus persica* and *P. dulcis* plants from Türkiye. *EFSA Journal* 21(1): e07735. https://doi.org/10.2903/j.efsa.2023.7735

Endes A (2021). Influence of culture media, temperature, pH and light regime on mycelial growth of *Ascochyta rabiei*. *International Journal of Agriculture Forestry and Life Sciences* 5(1): 87-93

Endes A & Kayım M (2022a). Morphological and molecular characterization of Botryosphaeriaceae species associated with dieback and gummosis on plum trees in Turkey. *Proceedings of the Bulgarian Academy of Sciences* 75(2): 295–302. https://doi.org/10.7546/CRABS.2022.02.16

Endes A & Kayım M (2022b). The Effect of temperature and culture media on mycelial growth of *Phytophthora citrophthora* causing gummosis, crown and root rot on lemon seedlings. *Journal of Turkish Phytopathology* 51(1): 21-26.

Endes A, Kayım M & Eskalen A (2016). First Report of *Lasiodiplodia theobromae*, *L. pseudotheobromae*, and *Diplodia seriata* causing bot canker and gummosis of nectarines in Türkiye. *Plant Disease* 100(11): 2321. https://doi.org/10.1094/PDIS-01-16-0036-PDN

Ezra D, Hershcovich M & Shtienberg D (2017). Insights into the etiology of gummosis syndrome of deciduous fruit trees in Israel and its impact on tree productivity. *Plant Disease* 101(8): 1354-1361. https://doi.org/10.1094/PDIS-12-16-1836-RE

Freitas T R, Santos J A, Silva A P & Fraga H (2023). Reviewing the adverse climate change impacts and adaptation measures on almond trees (*Prunus dulcis*). *Agriculture* 13(7): 1423. doi.org/10.3390/agriculture13071423

Garcia J F, Lawrence D P, Morales-Cruz A, Travadon R, Minio A, Hernandez-Martinez R, Rolshausen P E, Baumgartner K & Cantu D (2021). Phylogenomics of plant-associated Botryosphaeriaceae species. *Frontiers in Microbiology* 12: 652802. https://doi.org/10.3389/fmicb.2021.652802

Glass N L & Donaldson G C (1995). Development of primer sets designed for use with the PCR to amplify conserved genes from filamentous ascomycetes. *Applied and Environmental Microbiology* 61(4): 1323-1330. https://doi.org/10.1128/aem.61.4.1323-1330.1995

Goura K, Lahlali R, Bouchane O, Baala M, Radouane N, Kenfaoui J, Ezrari S, Hamss H E, Alami N E, Amiri S, Barka E A & Tahiri A (2023). Identification and characterization of fungal pathogens causing trunk and branch cankers of almond trees in Morocco. *Agronomy* 13(1): 130. https://doi.org/10.3390/agronomy13010130

Holland L A, Trouillas F P, Nouri M T, Lawrence D P, Crespo M, Doll DA, Duncan R A, Holtz B A, Culumber C M, Yaghmour M A, Niederholzer F J A, Lightle D M, Jarvis-Shean K S, Gordon P E & Fichtner E J (2021). Fungal pathogens associated with canker diseases of almond in California. *Plant Disease* 105(2): 346-360. https://doi.org/10.1094/PDIS-10-19-2128-RE

Inderbitzin P, Bostock R M, Trouillas F P & Michailides T J (2010). A six locus phylogeny reveals high species diversity in Botryosphaeriaceae from California almond. *Mycologia* 102(6): 1350–1368. https://doi.org/10.3852/10-006

Ismail A M, Cirvilleri G, Lombard L, Crous P W, Groenewald J Z & Polizzi G (2013). Characterisation of *Neofusicoccum* species causing mango dieback in Italy. *Journal of Plant Pathology* 95(3): 549-557. https://www.jstor.org/stable/23721576

Jiménez Luna I, Doll D, Ashworth V E, Trouillas F P & Rolshausen P E (2022). Comparative profiling of wood canker pathogens from spore traps and symptomatic plant samples within California almond and walnut orchards. *Plant Disease* 106(8): 2182-2190. https://doi.org/10.1094/PDIS-05-21-1057-RE

Kayim M, Endes A & Eskalen A (2015). First report of *Neofusicoccum parvum* and *Diplodia sp*. associated with wood canker and dieback on almond in Turkey. In: XVIII. International plant protection congress (IPCC), Berlin, Germany, pp 798.

Küçükyumuk C & Suarez D (2023). The combined effects of salinity and drought on young almond trees and physiological parameters. *Journal of Agricultural Sciences* 29(1): 171-187. https://doi.org/10.15832/ankutbd.984038

Ko Y Z, Liyanage W K, Shih H C, Tseng M N, Shiao M S & Chiang Y C (2023). Unveiling cryptic species diversity and genetic variation of *Lasiodiplodia* (Botryosphaeriaceae Botryosphaeriales) infecting fruit crops in Taiwan. *Journal of Fungi* 9(9): 950. https://doi.org/10.3390/jof9090950

Li Z, Wang Y T, Gao L, Wang F, Ye J L & Li G H (2014). Biochemical changes and defence responses during the development of peach gummosis caused by *Lasiodiplodia theobromae*. *European Journal of Plant Pathology* 138: 195-207. https://doi.org/10.1007/s10658-013-0322-4

Luo Y, Ma R, Barrera E, Gusella G & Michailides T J (2022). Effects of temperature on development of canker-causing pathogens in almond and prune. *Plant Disease* 106(9): 2424-2432. https://doi.org/10.1094/PDIS-01-22-0048-RE

Michailides T J, Inderbitzin P, Connell J H, Luo Y G, Morgan D P & Puckett R D (2017). Understanding band canker of almond caused by Botryosphaeriaceae fungi and attempts to control the disease in California. In VII International Symposium on Almonds and Pistachios 1219 (pp. 303-310). https://doi.org/10.17660/ActaHortic.2018.1219.46

Moral J, Morgan D, Trapero A & Michailides T J (2019). Ecology and epidemiology of diseases of nut crops and olives caused by Botryosphaeriaceae fungi in California and Spain. *Plant Disease* 103(8): 1809-1827. https://doi.org/10.1094/PDIS-03-19-0622-FE

Nouri M T, Lawrence D P, Yaghmour M A, Michailides T J & Trouillas F P (2018). *Neoscytalidium dimidiatum* causing canker, shoot blight and fruit rot of almond in California. *Plant Disease* 102(8): 1638-1647. https://doi.org/10.1094/PDIS-12-17-1967-RE

Olmo D, Armengol J, León M & Gramaje D (2016). Characterization and pathogenicity of Botryosphaeriaceae species isolated from almond trees on the island of Mallorca (Spain). *Plant Disease* 100(12): 2483-2491. https://doi.org/10.1094/PDIS-05-16-0676-RE

Ören E, Koca G, Gencer R & Bayraktar H (2020). First report of *Neoscytalidium novaehollandiae* associated with stem canker and branch dieback of almond trees. *Australasian Plant Disease Notes* 15(1): 17. https://doi.org/10.1007/s13314-020-00386-9

Özdemir B, Yılmaz A, Büyükkartal H N, & Okay Y (2019). Anatomical analysis of graft compatibility in some almond scionrootstock combination. *Journal of Agricultural Sciences* 25(1): 29-37. https://doi.org/10.15832/ankutbd.538985

Özer G, Türkölmez Ş & Derviş S (2022). First report of *Lasiodiplodia theobromae* causing dieback on almond (*Prunus dulcis*) in Turkey. *Journal of Plant Pathology* 104: 445–446. https://doi.org/10.1007/s42161-021-01018-6

Phillips A J L, Alves A, Abdollahzadeh J, Slippers B, Wingfield M J, Groenewald J Z & Crous P W (2013). The Botryosphaeriaceae: genera and species known from culture. *Studies in Mycology* 76: 51–167. https://doi.org/10.3114/sim0021

Phillips A J, Crous P W, & Alves A (2007). *Diplodia seriata*, the anamorph of "*Botryosphaeria obtusa''*. *Fungal diversity*, 25(1892): 141-55.

Pouzoulet J, Yelle D J, Theodory B, Nothnagel E A, Bol S & Rolshausen P E (2022). Biochemical and histological insights into the interaction between the canker pathogen *Neofusicoccum parvum* and *Prunus dulcis*. *Phytopathology* 112(2): 345-354. https://doi.org/10.1094/PHYTO-03-21-0107-R

Romero-Cuadrado L, López-Herrera C J, Aguado A & Capote N (2023a). Duplex real-time pcr assays for the simultaneous detection and quantification of Botryosphaeriaceae species causing canker diseases in woody crops. *Plants* 12(11): 2205. https://doi.org/10.3390/plants12112205

Romero-Cuadrado L, Picos M C, Camacho M, Ollero F J & Capote N (2023b). Biocontrol of almond canker diseases caused by Botryosphaeriaceae fungi. *Pest Management Science* https://doi.org/10.1002/ps.7919

Silva-Valderrama I, Úrbez-Torres J R & Davies T J (2024). From host to host: the taxonomic and geographic expansion of Botryosphaeriaceae. *Fungal Biology Reviews* 48: 100352. https://doi.org/10.1016/j.fbr.2023.100352

Slippers B & Wingfield M (2007). Botryosphaeriaceae as Endophytes and latent pathogens of woody plants: Diversity, ecology and impact. *Fungal Biology Reviews* 21: 90-106. https://doi.org/10.1016/j.fbr.2007.06.002

Slippers B., Crous P W, Denman S, Coutinho T A, Wingfield B D & Wingfield M J (2004). Combined multiple gene genealogies and phenotypic characters differentiate several species previously identified as *Botryosphaeria dothidea*. *Mycologia* 96(1): 83-101. https://doi.org/10.1080/15572536.2005.11833000

Sohrabi M, Mohammadi H, León M, Armengol J & Banihashemi Z (2020). Fungal Pathogens Associated with Branch and Trunk Cankers of Nut Crops in Iran. *European Journal of Plant Pathology* 157: 327–351. https://doi.org/10.1007/s10658-020-01996-w

The website of food and agriculture organization of the United Nations (FAO) (2022). Available online: https://www.fao.org/faostat/en/#data/QCL (accessed on 18.02.2024)

Thomidis T, Michailides T J & Exadaktylou E (2011). *Neofusicoccum parvum* associated with fruit rot and shoot blight of peaches in Greece. *European Journal of Plant Pathology* 131: 661–668. https://doi.org/10.1007/s10658-011-9840-0

Türkölmez Ş, Derviş S, Çiftçi O & Serçe Ç U (2016). First report of canker and dieback caused by *Botryosphaeria dothidea* on apple in Turkey. *Plant Disease* 100(6): 1237. https://doi.org/10.1094/PDIS-11-15-1334-PDN

Wang F, Zhao L, Li G, Huang J & Hsiang T (2011). Identification and characterization of *Botryosphaeria* sp. causing gummosis of peach trees in Hubei Province, central China. *Plant Disease* 95: 1378-1384. https://doi.org/10.1094/PDIS-12-10-0893

White T J, Bruns T, Lee S & Taylor J (1990). Amplification and direct sequencing of fungal ribosomal RNA genes for phylogenetics. In: Innis M, Gelfand D, Sninsky J & White T (eds.) PCR Protocols: A Guide to methods and applications. San Diego, California, pp. 315–322. https://doi.org/0.1128/aem.66.10.4356-4360.2000

Yang T, Groenewald J Z., Cheewangkoon R, Jami F, Abdollahzadeh J, Lombard L & Crous P W (2017). Families, genera, and species of Botryosphaeriales. *Fungal Biology* 121(4): 322-346. https://doi.org/10.1016/j.funbio.2016.11.001

Yeniay E & Şık A (2022). Risk analysis using geographic information systems by determining the factors affecting yield in plant production: a case study from Ankara, Turkey. *Journal of Agricultural Sciences* 28(4): 677-690. https://doi.org/10.15832/ankutbd.900997

Yildiz A, Benlioğlu K & Benlioğlu H S (2014). First report of strawberry dieback caused by *Lasiodiplodia theobromae*. *Plant Disease* 98(11): 1579. https://doi.org/10.1094/PDIS-11-13-1192-PDN

Zhang Z X, Deng D F, Qi W J, Fan S S, Cao Y, Huang J G & Liu Z Y (2013). *Botryosphaeria dothidea*, the causal agent of a new stem canker disease of Tatarian dogwood (*Cornus alba*) in China. *Australasian Plant Pathology* 42: 113-119. https://doi.org/10.1007/s13313-012-0197-4

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Determining Factors Affecting Agricultural Credit Demand: A Research in Erzurum Province, Türkiye

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ABSTRACT

The purpose of this research is to identify the variables that might influence the demand for low-interest business and investment loans given to Türkiye livestock and agricultural industries. A face-to-face survey of 384 producers who go on with their production operations in ten distinct Erzurum districts provided the data utilized in the study. Binary logistic regression analysis was used to identify the factors influencing credit use. The data shows that producers in the age groups of 20–30 are less likely to utilize credit than those in the 31–45 and 46–60 age groups. Credit use is higher among individuals involved in mixed production activities than in crop production only. Individuals who report being in excellent health have a higher likelihood of using credit than those who report being in bad health. Having a house of one's own increases the likelihood of using credit. Those whose production activity location is close to the district center are more likely to use credit. It has been shown that people are more likely to utilize if they say the guarantees that loan providers want are inexpensive, if they say they will carry on with their production, and if they say they are happy with the amount of expertise needed for production.

Keywords: Agricultural credit, Logistic regression, Marginal effect, Türkiye

1. Introduction

Agricultural and animal production is frequently mentioned as an indispensable sector for reasons such as people's survival, social development, providing input to other sectors and contributing to employment (Zhao et al. 2008; Ma et al. 2019; Bahşi & Çetin 2020; Wang et al. 2023). The health of this sector has significant impacts on the nation's key macroeconomic goals, such as job creation, poverty reduction, human resource development, and food security (Quddus & Kropp 2020). Due to economic factors, climatic conditions, decreasing soil quality, land fragmentation, etc., some limitations in production may be encountered and may constitute an obstacle to sustainability in agriculture. It implements support policies in order to increase the income of economic units operating in the agricultural sector, to protect consumers, to improve the production structure, to increase production, to increase efficiency and to mitigate or prevent fluctuations in agricultural product prices (Tuna 2011).

Agricultural support policies differ according to the level of development and needs of countries. According to the Organization for Economic Cooperation and Development (OECD), agricultural support policies implemented in Türkiye include direct payments to producers, high or low price applications in product prices, tax reductions and discounted credit applications, development of agricultural infrastructure, training, information production, distribution of information, etc.

In order to reduce the negative impact of dependency due to economic and other factors, the state in Türkiye provides subsidized business and investment loans to producers engaged in agricultural and animal production activities. Agricultural credit is an important factor in the development of the production and investment structure of the agricultural sector in both developed and developing countries and is an important instrument of agricultural development (Adanacioğlu et al. 2017). Financial support plays a critical role in facilitating sustainable growth and development of agricultural enterprises. Access to adequate and affordable financing is essential for farmers and agribusinesses to invest in modern technologies (Musagaliev & Dustova 2023). The literature on the impact of agricultural credit on producer income and output recognizes that producers' access to credit is important in agriculture (Akram et al. 2013; Ekwere & Edem 2014; Udoka et al. 2016; Nadolnyak et al. 2017; Amanullah 2019; Sagbo & Kusunose 2020; N.Anh et al.2020; Moahid et al. 2021; Novotná & Kočišova 2022; Hutchins 2023).

The aim of the study is to determine the economic and socio-demographic factors that may affect the demand of these loans extended to producers in order to support agricultural production and reduce the impact of economic, climatic, etc. dependency, as well as business characteristics by logistic regression analysis. The data used in the study were obtained through a face-to-face survey conducted to the producers who continue their production activities in 10 districts of Erzurum. A total of 384 producers were surveyed through random sampling and Binary Logistic Regression analysis was performed with the data obtained and marginal effects were examined. The literature study on the factors affecting agricultural credit demand is given in Table 1.

Table 1- Literature Review

Authors	*Data-Method*	*Analysis Method*	*Conclusion*
Katchova (2005)	2001 Agricultural Resource Management study data were used.	Probit Model	Farm income, business management strategies, age and risk aversion were found to affect the probability of using credit.
Oluwasola & Alimi (2008)	Data collected from a survey of 270 producers was used.	Tested with exponential regression models.	Interest rate, farm expenditures, farm size and savings are found to be the main determinants of loan demand.
Mpuga (2010)	Household survey data from 1992-93 and 1999-2000 were used.	Probit, Tobit and Multinominal Logit	It has been determined that educated and young producers are more likely to request loans, while female producers have lower credit requests and amounts.
Nouman et al. (2013)	Data were collected using a questionnaire administered to 80 respondents.	Ordinal Logistic Regression	Credit utilization was found to be significantly affected by marital status, farm size and education level.
Cheng and Ahmed (2014)	Data collected through a questionnaire survey of producers in four different districts were used.	Probit Model	Poor households and older age level are found to increase the likelihood of applying for loans from informal sources.
Ijioma and Osundu (2015)	Data were obtained through a questionnaire administered to 90 producers through random sampling.	Multiple Regression	Age, household size, cooperative membership, marital status, education level, enterprise size and total loans repaid were found to have an impact on credit utilization.
Fecke et al. (2016)	Data from the German Development Bank consisting of 68 430 observations covering the years 2010-2014 were used.	Ordinary Least Squares (OLS)	It has been determined that the interest rate has a negative effect on the demand for loans, and grace periods, gross value added in agriculture and job expectations have a positive effect on the demand for loans.
Asante-Addo et al. (2017)	Data were obtained through a questionnaire survey of approximately 150 producers.	Probit Model	Savings, membership in farmer organizations, and education of the household head were found to positively affect participation in credit programs.
Umanath et al. (2018)	National Sampling Survey data for 2012-2013 were used.	Heckman Sample Selection Model	Enterprise size, age, and having a credit or debit card increase the likelihood of accessing agricultural credit.
Ogundeji et al. (2018)	The data were obtained through a questionnaire administered to 100 farmers.	Probit, Tobit	Savings, scale of production, membership in farmers' associations and financial record keeping have a positive effect on access to credit, while high interest rates have a negative effect.
Hayran & Gül (2018)	239 farmers were surveyed with a questionnaire.	Binary Logistic Regression	Household size, cultivated planted area, cooperative membership positively affected agricultural credit use, while the variables of farmer's age, whether or not he/she received agricultural consultancy and the number of agricultural training programs attended in the last year negatively affected agricultural credit use.
Vovchak et al. (2018)	Sector data	Correlation-regression analysis	The demand for bank loans by small and medium-sized agricultural enterprises is largely driven by low interest rates.
Qin et al. (2019)	342 producers were surveyed and data were collected.	Heckman Two Stage Model	Cost of production, non-working family members, income level, and guarantee group membership were found to increase the use of microcredit.
Silong & Gadanakis (2019)	216 producers were surveyed and data were collected.	Logit Model	Education, group membership, household size and gender are found to be effective on loan demand.
Ofori et al. (2019)	The data were obtained through a questionnaire survey of 209 producers by stratified random sampling method.	Treatment Effect, Propensity Score Matching	Membership in a cooperative has no effect on agricultural income, value and quantity of agricultural inputs, but membership affects access to credit services and choice of technology.

Table 1- Literature Review (Continued)			
Lin et al. (2019)	2013 Household Finance survey data were used.	Probit Model	Age, family size, non-agricultural income, education level and informal borrowing were found to be effective on credit constraints.
Dang et al. (2019)	Data from 206 producers were used.	Multinomial Logit regression	Collateral was identified as the most important barrier to accessing formal credit.
Kumar et al. (2020)	Data from the National Survey Office's Debt and Investment Survey were used.	Cragg's Model	It has been determined that assets, land size, education level of the head of the family and gender have an effect on access to corporate credit.
Ullah et al. (2020)	In 2017, data were obtained through a survey of 395 randomly selected producers.	Binary Logistic Regression	A positive relationship was found between farm size, monthly income, access to information and asset status and credit utilization.
Khanal & Omobitan (2020)	Data were obtained through a survey of 104 producers using stratified random sampling.	Probit Model	Gender, off-farm work, amount of land owned, farm expertise, internet and smartphone use were found to have an effect on credit constraint.
Moahid & Maharjan (2020)	292 farmers were surveyed and data were obtained through a questionnaire.	Probit Model	It has been determined that crop diversity, education, number of adults in the household, and business size positively affect the demand for loans.
Hu et al. (2020)	Data were collected from 1422 producers through a questionnaire survey.	Probit Model	Collateral status, courage for credit, business type (sole proprietorship-company) were found to be factors affecting credit constraints. Gender, age and marital status are not effective on credit constraints.
Toure (2021)	In 2019, data was obtained through a survey conducted with 400 producers.	Logistic Regression	Access to credit, quantity of cotton sold, total area planted, quantity of other crops and sale price were identified as the factors that led to income growth.
Ojo et al. (2021)	Data were collected through a questionnaire survey of 183 producers from four provinces covering the years 2017-2018.	Probit Model	Location, education and drought experience were identified as factors affecting access to credit.
Lazaro & Alexis (2021)	Data collected from 300 producers identified through multi-stage sampling were used.	Binary Logistic Regression	Factors such as age, gender, education, household size, distance, awareness, and collateral were found to be determinants of credit demand.
Kahramanoğlu (2021)	153 producers were surveyed with a questionnaire.	Chi-square test	A significant relationship has been found between the increase in education, openness to innovations and following economic developments and turning to private banks.
Kuhn & Bobojonov (2021)	Life in Kyrgyzstan (LIK) dataset covering the years 2013-2016 is used.	Logit, Least Squares	The risk of credit default and the possibility of collateral loss are demand-side policies that prevent producers from applying for loans. Supply-side factors such as real credit constraints and demand for collateral significantly affect credit utilization ratios and loan amounts.
Manogna & Mishra (2022)	Survey data from the National Sample Research Office between 2012 and 2013.	Tobit Model	There is a positive relationship between producers' asset status, enterprise size and access to credit.
Gong & Elahi (2022)	Household Finance Survey (CHFS) data were used.	Propensity Score Matching, Benchmark Regression	It is stated that land transfer decreases the demand for credit, while the previous year's production amount positively affects the demand for credit. Age has a negative effect on utilization of agricultural credit.
Behera A. & Behera M. (2022)	Data was collected from 475 producers through a questionnaire survey.	Logit Model	Factors such as collateral problems, low awareness of farmers, low level of education, lack of financial institutions in villages, etc. were identified as constraints faced by farmers.
Wongpit & Sisengam (2022)	In 2019, data from a nationwide household survey was used.	Logit Model	Household size has a negative relationship with access to credit, household income has a negligible effect on credit demand, while savings has a positive effect.

2. Material and Methods

2.1. Data

The sampling framework of the research consists of producers in 10 different districts determined by random sampling method in Erzurum. These districts are Aziziye, Yakutiye, Palandoken, Aşkale Pasinler, Tekman, Karayazı, Horasan, Narman and Tortum, as seen in Figure 1. The data set in the research was obtained in 2023 through a face-to-face survey of producers engaged in agriculture and animal husbandry in these districts. During the meetings with the Erzurum Provincial Directorate of Agriculture, it was informed that a total of 28 594 producers were operating in the districts determined during the period to be surveyed.

Figure 1- Erzurum Province Sampling Frame (Google Earth 2023)

The following formula was used to determine the size of the sample mass to be surveyed.

$$n = \frac{\mathrm{NPQ}Z^2}{(N-1)d^2 + \mathrm{PQ}Z^2} \quad (1)$$

In this formula, n = Sample mass size, N = Acatch volume (number of producers operating in 10 districts), P = Rate of agricultural credit utilization, Q = Rate of non-use of agricultural credit (1-P), Z=(1-α) Z test value at level, α = Level of significance, d = Margin of error (tolerance) (Özer 2004).

Sample size after making the necessary calculations in the formula,

$$n = \frac{28594(0{,}5)(0{,}5)(1{,}96)^2}{(28594-1)0{,}05^2 + (0{,}5)(0{,}5)(1{,}96)^2} \cong 380$$

calculated as. A total of 384 survey data and binary logistic regression analysis were performed to examine the marginal effects. The distribution of the data obtained by districts is given in Table 2.

Table 2- Distribution of Participants by Districts

Districts	*Frequency*	*Percentage*
Aşkale	41	10.7
Aziziye	45	11.7
Palandöken	30	7.8
Yakutiye	36	9.4
Pasinler	54	14.1
Narman	31	8.1
Tekman	37	9.6
Horasan	37	9.6
Karayazı	39	10.2
Tortum	34	8.9
Total	384	100.0

2.2. Measures and variables

The dependent variable of the study is "Do you have subsidized agricultural loans?" It is a two-category (yes-no) answer variable to the question. These categories are defined with "0" if there is agricultural credit, and "1" if there is no agricultural credit. Independent variables are defined as dummy variables in order to measure the effects of their categories on the dependent variable; age (20-30, 31-45, 46-60 and 60+), number of people in the household, level of education, status of employment in another activity (no, yes, retired), field of production activity (vegetable, animal and mixed), market connection status (yes, no), state of health (good, bad), the idea that credit conditions are difficult (disagree, undecided, agree), opinion on whether the loan is advantageous or not (is it advantageous? / disagree, undecided, agree), presence of personal loans (yes, no), annual income (0-50 thousand TL, 51-100 thousand TL, 101-150 thousand TL, 151-200 thousand TL, 200 thousand TL+), Distance of the activity location from the district center (0-20 km, 21-30 km, 31+ km), use of mobile or internet banking (yes, no), credit card ownership (yes-no), his opinion about the affordability of the collateral level required for the loan (disagree, undecided, agree), the idea that the loans used will increase income(disagree, undecided, agree), the idea that I will continue production in the future (I disagree, I'm undecided, I agree), degree of satisfaction with the level of knowledge required for production (dissatisfied, satisfied), they are variables measured on ordinal and nominal scales, such as the level of satisfaction with the income obtained (I am not satisfied, I am satisfied).

2.3. Research methodology

With the data obtained from the producers in the survey application areas, frequency analyzes were first made in the SPSS 20 Package program. Then, chi-square independence tests, which are frequently used in practice, were performed to determine the relationship between the dependent variable and the independent variables. The dependent variable is the binary response variable expressing the credit utilization status. If the dependent variable is a binary response variable (yes-no), binary logistic regression analysis is used to examine the cause and effect relationship between the dependent variable and independent variables (Agresti 1996). Finally, binary logistic regression analysis was performed in the Stata 15 package program with the variables subjected to chi-square independence test and marginal effects and factors affecting agricultural credit demand were determined.

3. Results

3.1. Descriptive statistics and chi-square test

Business characteristics, credit-related considerations, socio-demographic and economic factors that may be effective in agricultural loan demand are shown in Table 3.

The share of producers using subsidized loans by age group was 8.3% for 20-30, 18.2% for 31-45, 20.8% for 46-60 and 5.2% for 61+. The share of producers working in another job and using loans in the total is 8.3%, the share of those working in another job but using loans is %39.8 and the share of retired people is 13.2%. The share of those engaged in crop production and using credit is 4.9%, the share of those engaged in animal production is 15.9%, and the share of those engaged in mixed production activities is 31.8%. The share of those who have a market connection in production activities and use credit in the total is 6.4%, while the share of those who do not have a market connection is 45.3%. The share of producers in good health who utilized loans was 39.3%, while the share of those in poor health was 13.3%. The share of those who own a house in the province or district and use a loan in the total is 17.2%, while the share of those who do not own a house is 35.4%.

The share of producers who used credit and disagreed that the conditions were difficult was 4.4%, the share of those who were undecided was 20.6% and the share of those who agreed was 27.6%. The share of producers who do not agree that the loans are advantageous and use loans is 15.1%, the share of those who are undecided is 16.9% and the share of those who agree is 26.6%. The share of those who disagree with the statement "Loans increase income" and use loans is 14.8%, the share of those who are undecided is 20.6%, and the share of those who agree is 17.2%. The share of those who disagree with the statement "I will continue production in the future" and use credit is 6.5%. The share of those who are undecided is 1.6% and the share of those who agree is 6.6%. The share of producers who agree with the statement "The required guarantees are suitable" and use loans is 22.1% in the total.

The share of borrowers with an annual income between TL 0-50 thousand is 3.9%, TL 51-100 thousand is 14.3%, TL 101-150 thousand is 12.8%, TL 151-200 thousand is 10.9% and TL 201 and above is 5.5%. The share of producers who have personal loans and use loans in the total is 6%, while the share of those who do not have a loan is 46.6%. The share of those who stated that the distance of the production activity location to the district center is 0-20 km and used credit is 27.9%, those whose distance is 21-30 km is 12.2% and those whose distance is 31 km + is 12.5%. The share of those who use mobile/internet banking and take out loans in the total is 34.1%, and the share of those who do not use it is 18.5%. The share of those who are not satisfied with their knowledge and use loans is 23.4%, while the share of those who are satisfied and use loans is 29.2%. While the share of those who are not satisfied with their income and use loans in the total is 34.1%, the share of those who are satisfied is 18.5%.

According to the chi-square independence test results in Table 3, the variables of working in another activity, having a personal loan and distance to the district center were not found to be significant. There is a significant relationship between all other variables and credit utilization status.

Table 3- Descriptive statistics and chi-square test results

Variables		*Subsidized Loan Utilization Status*		*n (%)*	X2	*P*
		Yes	*No*			
Age	20-30 age group	32(8.3)	3(0.8)	35(9.1)	33.940	0.000 [a]
	31-45 age group	70(18.2)	84(21.9)	154(40.1)		
	46-60 age group	80(89.4)	90(80.6)	170(6.5)		
	61 and above	20(13.2)	5(11.8)	25(25)		
Working status in another activity	No	153(39.8)	149(38.8)	302(78.6)	2.305	0.316
	Yes	32(8.3)	23(6)	38(14.3)		
	Retired	17(4.4)	10(2.6)	27(7)		
Production activity	Herbal	19 (4.9)	3(15.6)	22(5.7)	17.358	0.000[a]
	Animal	61(15.9)	38(9.9)	25.8(99)		
	Mixed	122(31.8)	141(36.7)	263(68.5)		
Is there a market connection?	Yes	28(6.4)	59(5.6)	87(22.7)	18.813	0.000[a]
	No	174(45.3)	123(32)	297(77.3)		
Health status	Good	66(39.3)	131(43.8)	319(83.1)	20.983	0.000 [a]
	Bad	51(13.3)	14(3.6)	65(16.9)		
Housing ownership status	Yes	66(17.2)	131(34.1)	197(51.3)	59.202	0.000 [a]
	No	136(35.4)	51(13.3)	187(48.7)		
The conditions to use the loan are difficult	Disagree	17(4.4)	116(30.2)	133(34.6)	158.962	0.000[a]
	Undecided	79(20.6)	1(0.2)	80(20.8)		
	I agree.	106(27.6)	65(16.9)	171(44.5)		
Subsidized loans are advantageous	Disagree	58(15.1)	38(9.9)	96(25)	77.337	0.000[a]
	Undecided	65(16.9)	3(0.8)	68(17.7)		
	I agree.	79(20.6)	141(36.7)	220(57.3)		
Do you have consumer credit?	Yes	23(6)	14(3.6)	37(9.6)	1.500	0.146
	No	179(46.6)	168(43.8)	347(90.4)		
Annual income status	0-50 thousand TL	15(3.9)	53(13.8)	68(17.7)	65.863	0.000[a]
	51-100 thousand TL	55(14.3)	102(26.6)	157(40.9)		
	101-150 thousand TL	49(12.8)	30(7.8)	79(20.6)		
	151-200 thousand TL	42(10.9)	13(3.4)	55(14.3)		
	201 thousand and above TL	21(5.5)	4(1)	25(6.5)		
Distance to district center	0-20 km	107(27.9)	111(28.9)	218(56.8)	2.549	0.280
	21-30 km	47(12.2)	34(8.9)	81(21.1)		
	31 and above km	48(12.5)	37(9.6)	85(22.1)		
Mobilbank/internet use case	Yes	131(34.1)	165(43)	296(77.1)	36.098	0.000 [a]
	No	71(18.5)	17(4.4)	88(22.9)		
Credit card usage status	Yes	78(20.3)	133(34.6)	211(54.9)	45.934	0.000 [a]
	No	124(32.3)	49(12.8)	173(45.1)		
The required collateral is affordable	Disagree	85(22.1)	109(28.4)	194(50.5)	120.893	0.000 [a]
	Undecided	95(24.7)	1(0.3)	96(25)		
	I agree.	22(5.7)	72(18.8)	94(24.5)		
Loans boost income	Disagree	57(14.8)	42(10.9)	99(25.8)	84.297	0.000 [a]
	Undecided	79(20.6)	7(1.8)	86(22.4)		
	I agree.	66(17.2)	133(34.6)	199(51.8)		
Will you continue production in the future?	Disagree	25(6.5)	8(2.1)	33(8.6)	7.764	0.021 [b]
	Undecided	6(1.6)	6(1.6)	12(3.1)		
	I agree.	171(44.5)	168(43.8)	339(88.3)		
Satisfaction with the level of knowledge required for production	Not Satisfied	90(23.4)	39(10.2)	129(33.6)	22.952	0.000 [a]
	I am satisfied	112(29.2)	143(37.2)	255(66.4)		
Satisfaction with your income	Not Satisfied	131(34.1)	64(16.7)	195(50.8)	33.758	0.000 [a]
	I am satisfied	71(18.5)	118(30.7)	189(49.2)		
Education Status					12.305	0.091 [c]
Number of people in the household					19.352	0.007 [a]

[a]P<0.01; [b]P<0.05; [c b]P<0.1

3.2. Model of estimation

In the study, there should be no multiple linear connections between the independent variables to be included in the model. Therefore, the multicollinearity test results performed before the model was established are given in Table 4. Those with a Variance Magnification Factor (VIF) value of 10 and above indicate a high level of multilinear connection, and those greater than 5 indicate a moderate level of multilinear connectivity (Alkan & Demir, 2009). It can be stated that there is no multicollinearity between the variables.

Table 4- Multicollinearity results for independent variables

Independent Variables	*VIF*	*1/VIF*
Age	1.60	0.627
Do you work in a job other than agricultural activity?	1.27	0.788
What is your production activity?	1.20	0.834
Do You Have a Market Connection at the Point of Sale of the Product?	1.29	0.766
Your health status?	1.26	0.791
Residential ownership status?	1.43	0.700
The requirements for obtaining a subsidized loan are difficult	1.34	0.746
Subsidized loans are advantageous	1.36	0.736
Do you have a personal loan?	1.29	0.774
Your annual income?	1.74	0.575
Distance of the place of production activity to the district center	1.14	0.879
Mobile/Internet banking use case	1.62	0.618
Your credit card usage status?	1.69	0.592
The required guarantees are at a level that can be met	1.14	0.874
Loans increase income	1.44	0.697
I will continue production in the future	1.12	0.890
Are you satisfied with the level of knowledge required for production?	1.14	0.876
Educational background	1.46	0.687
Number of people in the household	1.12	0.890
Mean VIF	1.35	

The estimated Binary logistic regression model estimation results and OR values are given in Table 5.

Binary logistic regression is not concerned with estimating the value of the dependent variable. Instead, the probability of the dependent variable taking the value 1 is estimated. (Alpar 2013). The dependent variable is the nominal variable "do you have subsidized loans (yes-no)?". For regression analysis, it was coded as yes=0, no=1. The results will be interpreted according to category 1 of the dependent variable.

According to binary logistic regression analysis, when OR <1, the factor of interest (relative to the reference) has little effect on the investigated situation. When OR >1, it has an increasing effect compared to the reference group (Alkan & Demir, 2019). As a result of the analysis, producers aged between 31-45 (OR 0.191; 95% CI = -3.303-0.003) and producers aged between 46-60 (OR = 0.126; 95% CI = -3.850 -0.291), 20-30 The odds ratio of not using credit is lower compared to producers in the age group between. According to the field of production activity, the odds ratio of producers engaged in mixed production (vegetable + animal production) (OR = 0.096; 95% CI = -4.111 -0.629) of not using credit is lower than the producers engaged in only plant production activities. Farmers with poor health status (OR=3.88; 95% CI= 0.218-2.497) have a higher odds ratio of not using credit than farmers with good health status. Producers who do not own a house in the city or district (OR=4.50; 95% CI=0.642-2.367) have a higher odds ratio of not using credit than producers who own a house. Manufacturers who are undecided about whether the credit conditions are difficult (OR=55.11; 95% CI= 1.532-6.485) and manufacturers who agree with the statement that the conditions are difficult (OR=6.56; 95% CI=0.973-2.789) have a higher odds ratio of not using credit than those who disagree with the statement that the credit conditions are difficult. Producers whose production location is 21-30 km away from the district center (OR=2.69; 95% CI=0.043-1.935) have a higher odds of not using credit than producers whose distance to the district center is 0-20 km.

Farmers who are undecided about whether the required collaterals are affordable (OR=92.33; 95% CI= 2.010-7.040) have a higher odds ratio of not using credit than those who disagree with the statement that the collaterals are affordable. Producers who are undecided whether to agree or not with the statement that they will continue production in the future (OR = 0.051; 95% CI = -5.825 -0.114) have a lower odds ratio of not using a loan than those who do not agree with this statement. Producers who are satisfied with the level of information required for production (OR = 0.415; 95% CI = -1.664 -0.091) have a lower odds ratio of not using credit than producers who are not satisfied with the level of information.

Table 5- Binary logistic regression analysis estimation results

Variables	*β*	*Standard Error*	*z*	*P>|z|*	*OR*	*[95% Conf. Interval] Lower Limit*	*Upper Limit*
Age (reference: 20-30)							
31-45 age group	-1.653316	0.841607	-1.96	0.049 [b]	.1914142	-3.302834	-0.0037969
46-60 age group	-2.070552	0.907934	-2.28	0.023 [b]	.1261162	-3.85007	-0.2910339
61 and above age group	-2.342141	1.395474	-1.68	0.093 [c]	.0961216	-5.07722	0.3929372
Work other than agricultural activities (reference: yes)							
No	0.324871	0.566381	0.57	0.566	1.383851	-0.7852158	1.434957
Retired	-0.837973	1.021333	-0.82	0.412	.4325864	-2.839748	1.163802
Production activity (reference: Herbal)							
Animal	-1.493949	0.928859	-1.61	0.108	.2244845	-3.314479	0.3265816
Mixed	-2.370258	0.888343	-2.67	0.008 [a]	.0934566	-4.111379	-0.6291374
2.market connection (reference: yes)	-.225045	0.50873	-0.44	0.658	.7984799	-1.222137	0.7720464
2.Your state of health (reference: good)	1.357852	0.581484	2.34	0.02 [b]	3.887833	0.2181652	2.497539
2.Housing ownership status (reference: yes)	1.504761	0.440103	3.42	0.001 [a]	4.503076	0.6421739	2.367348
Difficult credit conditions (reference: disagree)							
Undecided	4.009355	1.263608	3.17	0.002 [a]	55.1113	1.532728	6.485981
I agree	1.881261	0.463257	4.06	0.000 [a]	6.561772	0.9732934	2.789228
Loans are advantageous (reference: disagree)							
Undecided	-0.339069	1.107351	-0.31	0.759	.7124333	-2.509437	1.831299
I agree	-0.503324	0.451455	-1.11	0.265	.604518	-1.38816	0.381512
2.Consumer credit ownership (reference: yes)	-1.090707	0.694268	-1.57	0.116	.3359788	-2.451447	0.2700331
Annual income (reference: 0-50 thousand TL)							
51-100 thousand TL	0.143986	0.590416	0.24	0.807	1.154868	-1.013207	1.301179
101-150 thousand TL	0.109334	0.701614	0.16	0.876	1.115535	-1.265804	1.484472
151-200 thousand TL	-0.210328	0.81709	-0.26	0.797	.8103188	-1.811795	1.39114
201 thousand TL above	-1.175955	1.03762	-1.13	0.257	.3085241	-3.209653	0.8577428
Distance to district center (reference: 0-20 km)							
21-30 km	0.989734	0.482546	2.05	0.04 [b]	2.690518	0.0439615	1.935506
31 above km	-0.803263	0.530343	-1.51	0.13	.4478651	-1.842717	0.2361907
2. Mobile/Internet banking usage status (reference: yes)	1.017386	0.576562	1.76	0.078 [c]	2.765955	-0.1126536	2.147426
2.Credit card usage status (reference: yes)	0.416806	0.431603	0.97	0.334	1.517109	-0.4291197	1.262733
The required collateral is affordable (reference: disagree)							
Undecided	4.525408	1.283169	3.53	0.000 [a]	92.33358	2.010442	7.040374
I agree	-0.431994	0.468239	-0.92	0.356	.6492132	-1.349726	0.4857376
Loans increase income (reference: disagree)							
Undecided	1.298869	0.764991	1.7	0.09 [c]	3.665151	-0.200486	2.798225
I agree	-0.004768	0.449681	-0.01	0.992	.9952434	-0.8861255	0.8765897
Continue production in the future (reference: disagree)							
Undecided	-2.969472	1.456854	-2.04	0.042 [b]	.0513304	-5.824853	-0.1140903
I agree	-1.328541	0.737653	-1.8	0.072 [c]	.2648634	-2.774314	0.1172319
1.satisfied with the information needed for production.(reference: not satisfied))	-0.877794	0.401401	-2.19	0.029 [b]	.415699	-1.664526	-0.0910619
1.Satisfied with your income (reference: not satisfied)	--0.11117	0.432837	-0.26	0.797	.8947864	-0.9595154	0.7371748
Educational status	0.153727	0.186753	0.82	0.41	1.166172	-0.212302	0.5197552
Number of people in the household	-0.128733	0.161056	-0.8	0.424	.879209	-0.4443965	0.1869312

[a]P<.01; [b]P<.05; [c]P<.10; VIF: Variance Inflation Factor; OR: Odds Ratio

3.3. Marginal effects

The average marginal effects of the factors affecting the subsidized loan demands of producers engaged in agriculture and livestock are given in Table 6.

Table 6- Marginal effects estimates for factors affecting agricultural credit demand

Variables	*Marginal effects (%)*	*Standard Error*	*Z*	*P>Z*	*[95% Conf. Interval]*	
Age (referans:20-30 age group)						
31-45 age group	-63.1[b]	0.271	-2.33	0.020	-1.163643	-.099275
46-60 age group	-83.01[a]	0.308	-2.69	0.007	-1.43597	-.2256313
61 and above age group	-96.9	0.62.2	-1.56	0.120	-2.189348	.2517993
Work other than agricultural activity (reference: no)						
Yes	14.74	0.252	0.59	0.558	-.3461207	.6408651
Retired	-42.2	0.545	-0.77	0.439	-1.490862	.6473191
Production activity (reference: Herbal)						
Animal	-51.8[c]	0.128	-1.78	0.075	-1.087559	.051689
Mixed	-91.6[a]	0.142	-3.39	0.001	-1.445245	-.3864712
2. market connection (referans: evet)						
No	-10.4	0.231	-0.45	0.654	-.5564631	.3493587
2.Your state of health (reference: good)						
Bad	57.3[a]	0.221	2.59	0.010	.1390903	1.006372
2.Housing ownership status (reference: yes)						
No	69.7[a]	0.204	3.42	0.001	.2969891	1.095911
Difficult credit conditions (reference: disagree)						
Undecided	157.3[a]	0.313	5.02	0.000	.958175	2.187027
I agree	95.6[a]	0.252	3.79	0.000	.4620364	1.450034
Loans are advantageous (reference: disagree)						
Undecided	-15.3	0.513	-0.30	0.766	-1.160379	.853916
I agree	-23.1	0.204	-1.13	0.258	-.6315253	.1693095
2.Consumer credit ownership (reference: yes)						
No	46.6[c]	0.270	-1.73	0.085	-.9952609	.0634263
Annual income (reference: 0-50 thousand TL)						
51-100 thousand TL	6.62	0.273	0.24	0.809	-.4700685	.6024783
101-150 thousand TL	5.04	0.324	0.16	0.870	-.5854964	.68638
151-200 thousand TL	-10	0.389	-0.26	0.797	-.8634588	.6634304
201 thousand TL above	60.7	0.559	-1.08	0.278	-1.703751	.4901212
Distance to district center (reference: 0-20 km)						
21-30 km	42.3[b]	0.197	2.14	0.032	.0353201	.8099466
31 above km	-40.6	0.276	-1.47	0.142	-.9467555	.1355305
2. Mobile/Internet banking usage status (reference: yes)						
No	44.2[c]	0.233	1.90	0.058	-.0144303	.8991869
2.Credit card usage status (reference: yes)						
No	19.3	0.198	0.97	0.331	-.1959245	.5816758
The required collateral is affordable (reference: disagree)						
Undecided	122.5[a]	0.187	6.55	0.000	.8584678	1.591977
I agree	-21.9	0.243	-0.90	0.367	-.6966954	.2577277
Loans increase income (reference: disagree)						
Undecided	54.2[c]	0.294	1.84	0.066	-.0352973	1.119257
I agree	-2	0.214	-0.01	0.992	-.4222193	.4176751
Continue production in the future (reference: disagree)						
Undecided	-142.7[c]	0.799	-1.78	0.074	-2.995168	.1400782
I agree	-54.6[b]	0.266	-2.04	0.041	-1.068715	-.0224059
1.satisfied with the information needed for production.(reference: not satisfied))	-39.7[b]	0.177	-2.25	0.025	-.7438899	-.050727
1.Satisfied with your income (reference: not satisfied)	-5.2	0.202	-0.26	0.797	-.4477021	.3440087
Educational status	7.2	0.870	0.82	0.411	-.0990238	.2423418
Number of people in the household	-6	0.0751	-0.80	0.424	-.2072024	.0871861

[a]P<.01; [b]P<.05; [c]P<.10

According to marginal effects, producers in the age group of 31-45, 46-60 are 63.1% and 83.01% less likely not to use credit than producers in the age group of 20-30, respectively. Producers engaged in mixed production activities are 91.6% less likely not to use credit than producers engaged only in crop production activities.

Producers in poor health are 57.3% more likely not to use credit than producers in good health. Producers who do not have a house in the province or district are 69.7% more likely to not use a loan than producers who do have a house. Producers who agree that the conditions for using credit are difficult are 95.6% more likely not to use credit than those who disagree. Producers with a distance of 21-30 km from the district center of the production activity are 42.3% more likely not to use credit than producers with a distance of 0-20 km from the district center.

Those who are undecided about whether they agree or disagree with the statement "requested collaterals can be met" are 122.5% more likely not to use credit than those who disagree with this statement. Those who agree with the statement that I will continue production in the future are 54.5% less likely to not use credit than those who do not agree with this statement. Those who are satisfied with the level of knowledge required for production are 39.7% less likely not to use credit than those who are not satisfied with the level of knowledge.

When marginal effects are analyzed, no statistically significant relationship is found between the probability of using loans and employment status, having another job, having a market connection, whether the loans are advantageous or not, annual income, credit card ownership, level of satisfaction with income, education level and number of people in the household. There is a relationship between personal loan assets ($p=0.085$), mobile banking usage status ($p=0.058$), the idea that loans will increase income (undecided $p=0.066$) the probability of using credit at the $P<0.10$ significance level.

4. Discussion

Subsidized operating and investment loans have been allocated to the agriculture and livestock sector in Türkiye for many years. These loans apply different interest rates to different production areas. Some of them have zero interest and some of them have 25%, 50% or 75% interest discount. Producers who want to benefit from these loans must meet the general and special conditions specified in the communiqué issued for these loans and determining the technical principles. Producers who do not meet the conditions can access the capital they need at current interest rates without benefitting from the discounted interest rate.

The aim of this study is to determine the economic and socio-demographic factors that may affect the demand for subsidized agricultural loans in Türkiye, as well as the characteristics of the enterprises within the scope of Erzurum province. As a result of the analysis, it was found that the variables of age, production activity, health status, home ownership status, difficulty of loan conditions, distance, affordability of the required guarantees, the idea of continuing production in the future, and satisfaction with the level of knowledge required for production were statistically significant on loan demand. There is no statistically significant relationship between the likelihood of using loans and employment status, having a market connection, whether the loans are advantageous or not, annual income, credit card ownership, satisfaction level with the income obtained, education level and the number of people in the household.

According to the results of the analysis, producers at lower age levels are more likely not to use credit. Producers in the 46-60 age group are 83.01% less likely not to use credit than those in the 20-30 age group. Similar results were found in many studies in the literature (Katchova 2005; Umanath et al. 2018; Lazaro & Alexis 2021). This can be explained by the fact that producers at older age levels gain experience and have the necessary knowledge. It has been stated that there is a negative relationship between age and the probability of using credit (Hayran & Gül 2018; Gong & Elahi 2022). Lin et al. (2019) stated that age has an effect on credit constraint, and Hu et al. (2020) stated that it does not have an effect on credit constraint.

Producers whose field of production activity is mixed production (plant and animal) are 91.6% less likely not to use credit. Producers in poor health are 57.3% more likely not to use credit than producers in good health. Producers who own their own houses are more likely to use credit. Producers without a house are 69.7% more likely not to use credit than those with a house. The fact that the collateral required by credit providers can be covered by the houses in question may explain why home ownership may increase the probability of loan utilization. In the literature, it is stated that producers' asset levels have a positive effect on access to credit (Ullah et al. 2020; Akdemir et al. 2021; Manogna & Mishra 2022).

Producers who do not agree that the conditions for using credit are difficult are more likely to use credit. Producers who agree that the conditions for using credit are difficult are 95.6% more likely to not use credit than those who disagree with the statement that the conditions are difficult. As the distance of the production activity location to the district center where the loan application can be made increases, the possibility of using a loan decreases. Producers whose distance to the district center is 21-30 km are 42.3% more likely to not use credit than producers whose distance is 0-20 km. Lazaro & Alexis (2021) stated in their study that distance has an impact on loan demand.

Those who are undecided about whether they agree with the statement that the required collateral is affordable are 122.5% more likely to not use a loan than those who do not agree with this statement. There are studies in the literature stating that the desired guarantees have an impact on the use or restriction of credit (Lazaro & Alexis 2021; Kuhn & Bobojonov 2021; Hu et al. (2020); Dang et al. (2019); Behera & Behera (2022). Those who agree with the statement "I will continue production in the future" are 54.5% less likely to use credit than those who disagree with this statement. Those who are satisfied with the level of knowledge are 39.7% less likely to not use credit than those who are not satisfied. There are similar studies stating that awareness of loans has an impact on loan demand (Lazaro & Alexis (2021); Behera & Behera (2022)).

Healthy producers are likely to be in business and use loans for agricultural needs. Additionally, financing institutions tend to give loans to healthy, young and middle-aged producers. This may explain why healthy individuals are more likely to use credit.

Many of the producers who do not use credit think that the conditions are difficult and avoid applying for credit, although they do not have much information about credit products and the credit granting process. Producers who want to continue their production activities in the future are more likely to use loans. Frequent fluctuations in production costs and sales prices of products do not satisfy manufacturers. For this reason, ensuring stability in production costs and sales prices is seen as a confidence-increasing factor in the sector. Producers who have or may experience problems in terms of collateral cannot access these loans or are one step behind when it comes to loan applications. Policy makers, taking into account intelligence inquiries to producers experiencing collateral problems, and providing collateral support to business owners will increase the demand for these loans and the amount of loans used.

The research may be biased as it is the data obtained through survey questions directed to the producers. The questions for determining the loan request are multiple choice and open-ended questions are not included. This may prevent manufacturers from giving an explanatory answer to their thoughts.

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References

Adanacioğlu H, Artukoğlu M & Güneş E (2017). Analysis of agricultural credit performance in Turkey by multi-dimensional scaling approach. *Journal of Agricultural Economics* 23(2): 195-204 (In Turkish) https://doi.org/10.24181/tarekoder.364932

Agresti A (1996). *An Introduction to Categorical Data Analysis.* NY: John Wiley & Sons

Akdemir Ş, Miassi Y, Açıksarı Y Ş & Keskin F (2021). Producers' access to agricultural credit in Turkey: the case of Adana province. *Ciência Rural* 51. https://doi.org/10.1590/0103-8478cr20200353

Akram W, Hussain Z, Ahmad N & Hussain I (2013). Does agriculture credit affect production efficiency? frontier production function approach. *Pakistan Economic and Social Review* pp.179-190

Alkan Ö & Demir A (2019). Analysis of factors effecting the success of quitting tobacco use by logistic regression. *Ataturk University Journal of Economics & Administrative Sciences* 33(4): 1227-1244(In Turkish)

Alpar R (2013). Applied Multivariate Statistical Methods. *Ankara: Detay Anatolia Academic Publishing Co. Ltd.*(In Turkish)

Amanullah W J, Khan I, Channa S A & Magsi H (2019). Farm level impacts of credit constraints on agricultural investment and income. *Pak. J. Agr. Scen* 56(2): 511-521. https://doi.org/10.21162/PAKJAS/19.7872

Anh N T, Gan C & Anh D L T 2020. Does credit boost agricultural performance? evidence from Vietnam. *International Journal of Social Economics* 47(9): 1203-1221. https://doi.org/10.1108/IJSE-04-2020-0238

Asante-Addo C, Mockshell J, Zeller M, Siddig K & Egyir I S (2017). Agricultural credit provision: what really determines farmers' participation and credit rationing? *Agricultural Finance Review* 77/2: 239-256. https://doi.org/10.1108/AFR-02-2016-0010

Bahşi N & Çetin E (2020). Determining of agricultural credit impact on agricultural production value in Turkey. *Ciência Rural* 50(11) https://doi.org/10.1590/0103-8478cr20200003P

Behera A R & Behera M (2022). Access and repayment of institutional agricultural credit by farmers in tribal areas of odisha: trends, determinants and policy measures. *Journal of Asian and African Studies* https://doi.org/10.1177/00219096221117075

Cheng E & D Ahmed A (2014). The demand for credit, credit rationing and the role of microfinance: evidence from poor rural counties of china. *China Agricultural Economic Review* 6(2): 295-315. https://doi.org/10.1108/CAER-07-2012-0076

Dang H D, Dam A H T, Pham T T & Nguyen T M T (2019). Determinants of credit demand of farmers in lam dong, Vietnam: a comparison of machine learning and multinomial logit. *Agricultural Finance Review* 80(2): 255-274. https://doi.org/10.1108/AFR-06-2019-006 1

Ekwere G E & Edem I D (2014). Evaluation of agricultural credit facility in agricultural production and rural development. *Global Journal of Human-Social Science: B Geography, Geo-Sciences, Environmental Disaster Management* 14(3): 19-26

Fecke W, Feil J-H & Musshoff O (2016). Determinants of loan demand in agriculture: empirical evidence from Germany, *Agricultural Finance Review*, Vol. 76 No. 4, pp. 462-476. https://doi.org/10.1108/AFR-05-2016-0042

Gong M & Elahi E (2022). A nexus between farmland rights, and access, demand, and amount of agricultural loan under the socialist system of China. *Land Use Policy*, 120, https://doi.org/10.1016/j.landusepol.2022.106279

Hayran S & Gül A (2018). Factors affecting farmers' decisions on agricultural credit usage in Mersin province. *Journal of the Institute of Science and Technology* 8(1): 271-277. https://doi.org/10.21597/jist.407885

Hu L, Lopez R A & Zeng Y (2020). Determinants of credit constraints for agricultural wholesalers in China. *International Food and Agribusiness Management Review* 23(4): 563-577. https://doi.org/10.22434/IFAMR2019.0161

Hutchins J (2023). The US farm credit system and agricultural development: evidence from an early expansion 1920–1940. *American Journal of Agricultural Economics* 105(1): 3-26. https://doi.org/10.1111/ajae.12290

Ijioma J C & Osondu C K (2015). Agricultural credit sources and determinants of credit acquisition by farmers in Idemili local government area of anambra state. *Journal of Agricultural Science and Technology B* 5(1): 34-43. https://doi.org/10.17265/2161-6264/2015.01.004

Kahramanoğlu A (2021). Credit use of agricultural producers in the context of the banking system and analysis of production finance: the case of Bafra. *Turkish Journal of Agriculture - Food Science and Technology* 9(3): 615–620. https://doi.org/10.24925/turjaf.v9i3.615-620.4157

Katchova, A.L. 2005. Factors affecting farm credit use, *Agricultural Finance Review*, 65(2): 17-29. https://doi.org/10.1108/00214660580001164

Khanal A R & Omobitan O (2020). Rural finance, capital constrained small farms, and financial performance: findings from a primary survey. *Journal of Agricultural and Applied Economics* 52(2): 288-307. https://doi.org/10.1017/aae.2019.45

Kuhn L & Bobojonov I (2021). the role of risk rationing in rural credit demand and uptake: lessons from Kyrgyzstan. *Agricultural Finance Review* 83(1): 1-20. https://doi.org/10.1108/AFR-04-2021-0039

Kumar A, Das R, Aditya K S, Bathla S & Jha G K (2020). Examining ınstitutional credit access among agricultural households in eastern İndia: trends, patterns and determinants. *Agricultural Finance Review* 81/2: 250-264. https://doi.org/10.1108/AFR-04-2020-0054

Lazaro A M & Alexis N (2021). Determinants of credit demand by smallholder farmers in Morogoro, Tanzania. *African Journal of Agricultural Research* 17(8): 1068-1080. https://doi.org/10.5897/AJAR2020.15382

Lin L, Wang W, Gan C, Cohen D A & Nguyen Q T (2019). Rural credit constraint and informal rural credit accessibility in China. *Sustainability* 11(7): 1935. https://doi.org/10.3390/su11071935

Ma L, Long H, Zhang Y, Tu S, Ge D & Tu X (2019). Agricultural labor changes and agricultural economic development in China and their implications for rural vitalization. *Journal of Geographical Sciences* 29: 163-179. https://doi.org/10.1007/s11442-019-1590-5

Manogna R L & Mishra A K (2022). Determinants of indebtedness and institutional credit to rural agricultural households: an empirical evidence from South India. *International Journal of Social Economics*. 49(9): 1387-1400. https://doi.org/10.1108/IJSE-09-2020-0614

Moahid M, Ghulam D K, Yoshida Y, Joshi N P & Keshav L M (2021). "Agricultural Credit and Extension Services: Does Their Synergy Augment Farmers' Economic Outcomes?", *Sustainability* 13(7): 3758. doi:https://doi.org/10.3390/su13073758

Moahid M, Ghulam D K, Yoshida Y, Joshi N P & Keshav L M (2021). Agricultural credit and extension services: does their synergy augment farmers' economic outcomes?", *Sustainability* 13(7): 3758. https://doi.org/10.3390/su13073758

Mpuga P (2010). Constraints in access to and demand for rural credit: evidence from Uganda. *African Development Review*. 22(1): 115-148. https://doi.org/10.1111/j.1467-8268.2009.00230.x

Musagaliev A & Dustova M (2023). Fertile grounds: econometric analysis of financial support for agricultural enterprises. In BIO Web of Conferences (Vol. 66, p. 14012). EDP Sciences.

Nadolnyak D, Shen X & Hartarska V (2017). Farm income and output and lending by the farm credit system. *Agricultural Finance Review*, 77(1): 125-136. https://doi.org/10.1108/AFR-03-2016-0020

Nouman M, Siddiqi M, Asim S & Hussain Z (2013). Impact of socio-economic characteristics of farmers on access to agricultural credit. *Sarhad Journal of Agriculture* 29(3): 469-476.

Novotná A & Kočišova K (2022). The role of banks in financing the slovak agricultural sector. *AGRIS on-Line Papers in Economics and Informatics* 14(1): 81-94. https://doi.org/10.7160/aol.2022.140107

OECD (Organisation for Economic Co-operation and Development) 2023., https://stats.oecd.org/# Access date: 01.02.2023.

Ofori E, Sampson G S & Vipham J (2019). The effects of agricultural cooperatives on smallholder livelihoods and agricultural performance in cambodia. *In Natural Resources Forum* 43(4): 218-229. https://doi.org/10.1111/1477-8947.12180

Ogundeji A A, Donkor E, Motsoari C & Onakuse S (2018). Impact of access to credit on farm income: policy implications for rural agricultural development in Lesotho. *Agrekon* 57(2): 152-166.

Ojo T O, Adetoro A A, Ogundeji A A & Belle J A (2021). Quantifying the determinants of climate change adaptation strategies and farmers' access to credit in south Africa. *Science of The Total Environment* 792 pp https://doi.org/10.1016/j.scitotenv.2021.148499

Oluwasola O & Alimi T (2008). Determinants of agricultural credit demand and supply among small-scale farmers in Nigeria. *Outlook on Agriculture* 37(3): 185-193. https://doi.org/10.5367/000000008785915421

Özer H (2004). Econometric models with qualitative variables: Theory and an application, *Ankara: Nobel Publishing Distribution*. (In Turkish)

Qin M, Wachenheim C J, Wang Z & Zheng S (2019). Factors affecting chinese farmers' microcredit participation. *Agricultural Finance Review* 79(1): 48-59. https://doi.org/10.1108/AFR-12-2017-0111

Quddus A & Kropp J D (2020). Constraints to agricultural production and marketing in the lagging regions of Bangladesh. *Sustainability* 12(10): 3956. https://doi.org/10.3390/su12103956

Sagbo N S M & Kusunose Y (2020). Does experience with agricultural loans improve farmers' well-being? evidence from Benin. *Agricultural Finance Review* 81(4): 503-519. https://doi.org/10.1108/AFR-06-2020-0082

Silong A K F & Gadanakis Y (2019). Credit sources, access and factors influencing credit demand among rural livestock farmers in Nigeria. *Agricultural Finance Review* 80(1): 68-90. https://doi.org/10.1108/AFR-10-2018-0090

Toure L (2021). Effect of equipment credit on the agricultural income of cotton producers in Mali. *Journal of Economics, Management and Trade* 27(2): 41-58. https://doi.org/10.9734/jemt/2021/v27i230329

Udoka C O, Mbat D O & Duke S B (2016). The effect of commercial banks' credit on agricultural production in Nigeria. *Journal of Finance and Accounting* 4(1): 1-10

Ullah A, Mahmood N, Zeb A & Kächele H (2020). Factors determining farmers' access to and sources of credit: evidence from the rain-fed zone of Pakistan. *Agriculture* 10(12): 586. https://doi.org/10.3390/agriculture10120586

Umanath M, Paramasivam R, Kavitha V & Thangadurai T (2018). Determinants of demand for formal agricultural credit in rural India. *Asian Journal of Agricultural Extension, Economics & Sociology* 28(1): 1-7

Vovchak O D, Halkiv L & Demchyshyn M Y (2018). The condition and problems of Ukraine's agricultural enterprises banking crediting development. *Financial and Credit Activity-Problems of Theory and Practice* 3(26): 29-37

Wang Y, Lu H, Chen Y, Yang P, Cheng X & Xie F 2023. The impact of farmland management rights mortgage loan on the agri-food industrial agglomeration: case of Hubei province. *Land* 12(7): 1389. https://doi.org/10.3390/land12071389

Wongpit P & Sisengnam K (2022). Determinants of farmers' access to credit in the lao people's democratic republic. *Applied Economics Journal* 29(2): 124-138. https://doi.org/10.22004/ag.econ.334654

Yusuf T U N A (2011). State intervention in agricultural product prices and the history of intervention pricing policy in Turkey. *Istanbul University Faculty of Economics Journal* 47: 1-4. (In Turkish)

Zhao J, Luo Q, Deng H & Yan Y (2008). Opportunities and challenges of sustainable agricultural development in China. *Philosophical Transactions of the Royal Society B: Biological Sciences* 363(1492): 893-904

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Investigation of Effect of Labour and Road Infrastructure on Fermented Dairy Production Capacity in Upstream Fermented Dairy Supply Chain

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ABSTRACT
Scope of the study focuses on fermented dairy products because, they constitute very large and important part of human diet. These products are very healthy because, they have some health benefits. 2731 fermented dairy processors in 227 sub-sectors in 48 cities have been investigated to determine the effect of the length of roads, the number of white-collar and blue-collar employees on fermented dairy production capacity. To do that, Generalized Linear Model has been utilized. Consequently, results state that the number of blue-collar employees has a positive effect on fermented dairy production capacity at 0.001 significance while the number of white-collar employees does not have a significant effect on the fermented dairy production capacity. On the other hand length of road has a positive effect on the fermented dairy production capacity at 0.10 significance level.

Keywords: Fermented dairy products supply chain, Labour, Road infrastructure, Fermented dairy production capacity

1. Introduction

Fermented dairy products are focused on in the study because of their crucial effects for human health. The most common produced fermented dairy products in Turkey are cheese, Kashar cheese, yogurt, kumis kefir and butter milk (Akın & Cevger 2019). However dairy processors which produce 13 different fermented products are included in the study. Cultured dairy products are a fruit of a promising technology. Most companies produce dairy proteins such as casein and whey by fermentation of certain microorganisms or the use of bioreactors (Krampe & Fridman 2022). Fermented dairy products are derived from fermentation process of milk. Fermentation is a cheap, common process in food- beverage sectors (Dos Reis et al. 2017). The fermentation process is done by utilizing suitable as well as harmless microorganisms.

Main types of fermented dairy products are cheese, yogurt, fermented milk, butter milk, kumis, kefir (García et al.2020). Fermented dairy products constitute very large and important part of human diet. These products are very healthy because they have some health benefits for human body.

Fermented dairy products have immunological, anti-carcinogenic, immunomodulatory, anti-allergens, antioxidant, hypocholesterolemic, bone and hypotensive effects on human body (Shafiee & Sharifi 2017). These effects are very crucial for humans to stay healthy. Because of these health benefits for human body scope of the study focuses only on fermented dairy products.

There are 81 cities in Turkey however, 48 cities constitute the scope of the study because of database in Turkey lacks proper data in fermented dairy products. Actors of the whole fermented dairy supply chain are given in Figure 1. Consequently, all actors of fermented dairy supply chain deserve attention in the related dairy supply chain studies. But due to time as well as monetary constraint. Because, empirical findings show processors of dairy food products add the highest value compared to all the other members operating in the milk processing supply chain (Nahar et al. 2022) the study only focuses on milk processors operating in Turkey.

The important issue in dairy supply chain is transport infrastructure and condition of roads. Babu et al. (2015) conducted a study in India. The authors conducted swot analysis in Indian dairy supply chain. According to the study, poor transport

infrastructure in dairy supply chain was found to be one of the greatest challenges in dairy business. Consequently, in this study impact of main roads on fermented dairy production capacity is investigated.

Leonardo et al. (2015) emphasizes that the most important reason of inefficiency in farm production is quality of labour. According to Janssen (2013), the source of inefficiency in food production is lack of reliable workforce. Additionally, Fassio et al. (2006) states that dairy production should be organized in a more rationalized manner, the production activity will need more professional workforce.

In any case, labour productivity is one the of most important components in global dairy production (Střeleček et al. 2007).

Consequently, the purpose of the study is to investigate the impact of labour and road infrastructure on production capacity in upstream fermented dairy supply chain. In this context, variables related to labour and road infrastructure are independent variables while production capacity is considered as a dependent variable in the model in which GLM has been deployed to investigate the effect of labour and road infrastructure on production capacity.

This study has some uniqueness in the literature, to the best of our knowledge, the study is the first ever study investigating effect of labour and road infrastructure on the production capacity in fermented dairy products also it is the first ever study in related literature that has the purpose of investigating the effect of different workforce categories (skilled, unskilled workforce) on production of fermented dairy products.

The other uniqueness of this study is to take human resource (white-collar, blue-collar employees) and logistics (length of road) into consideration as variables in the study.

The study starts with explaining the importance of workforce in food especially in dairy production. After that, snapshot of milk supply chain is provided, health benefits of fermented dairy products are mentioned, importance of logistics infrastructure for fermented dairy products is explained, related literature review is given, model of the of the study is outlined finally, the study is concluded with conclusion remarks also caveats in the study.

2. Importance of Workforce in Food and Dairy Production

Food sector is regarded as a low-tech sector just as other traditional sectors. Production of dairy products in food sector employs higher percentage of labour like other low-tech manufacturing sector as opposed to high-tech or middle-tech manufacturing sectors (Sargent & Matthews 2008) that is why, both blue-collar and white-collar employees working in fermented dairy processors are addressed in the study.

Eurostat (2017) categorizes subsectors of manufacturing sector into high-tech, high-middle-high tech, middle-low tech and low- tech sector based on their technological intensity. Low technologically intensive sectors are regarded as labour intensive sectors in which labour is used predominately in manufacturing processes (Liu et al. 2014). Food sector is also regarded as a low-tech sector just as other traditional sectors. Production of dairy products in food sector employs higher percentage of labour like other low-tech manufacturing sector as opposed to high-tech or middle-tech manufacturing sector (Sargent & Matthews 2008). Most part of labour requirement in food and dairy production is met by family members (Ojo 2004; Nmadu et al. 2015; Kumari et al. 2020) despite this, cost of labour is about 35% of all other associated costs in food and dairy production (Albarrân-Portillo et al. 2015) especially, in some specialty food production areas for example in vine production in U.S. Labour cost makes up 60% of total costs. Labour shortage is the greatest impediment in production (Rutledge & Mêrel 2022).

Although, fermented dairy products which constitute the focus of the study are categorized in low-tech production sector these products require some specialized processes to prepare or produce. This means that fermented dairy products sector requires more professional namely skilled workforce compared to other traditional food production sectors.

3. Importance of Logistics Infrastructure for Fermented Dairy Products in Turkey

Figure 1 elucidates the milk processing supply chain. The milk processing supply chain consists of all the relevant members beginning from the input supplier to final customers (Dani 2015).

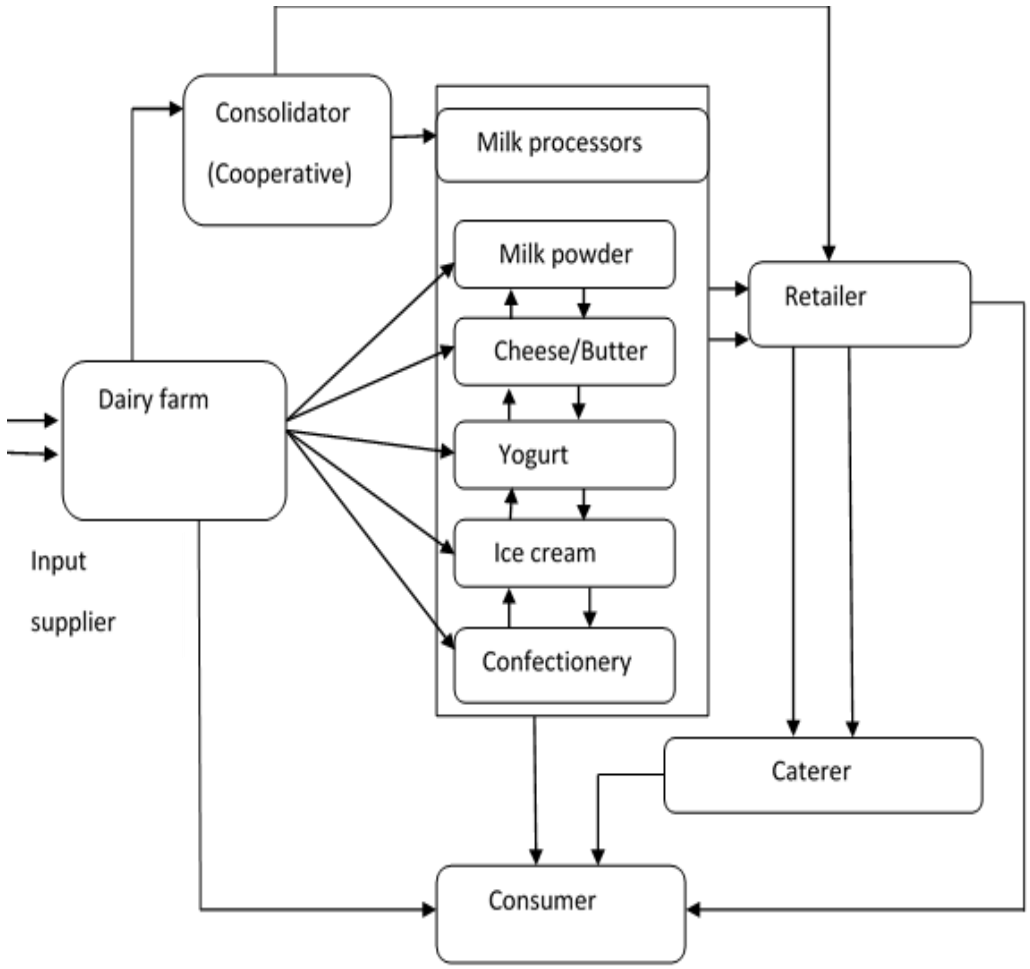

Figure 1- Anatomy of a Milk Processing Supply Chain. Source: Dani, S. (2015). Food supply chain management and logistics: From farm to fork. London: Kogan Page Publishers, p. 13.

All the members of the milk processing supply chain add value to the milk on its journey of becoming a final product throughout the whole supply chain. However, empirical findings show that processors of dairy food products add the highest value compared to all the other members operating in the milk processing supply chain (Nahar et al. 2022). That is why, the study only focuses on milk processors operating in Turkey.

The most common produced fermented dairy products in Turkey are cheese, Kashar cheese, yogurt, kumis kefir and butter milk (Akın & Cevger 2019).

Daily milk requirement is determined by planned production quantity in Turkey. Raw milk should be used within 48 hours. That is why, raw milk is transported to milk factory for the next day production. Raw milk should be stored in a cool condition both in the phases of milk collecting and dairy production. Cold chain in logistics activities of dairy product is very vital. The other process is in dairy production is heating raw milk for a sterilization process (Malliaroudaki et al. 2022). After this procedure dairy products are not yet ready for distribution after production because, all products are kept in quarantine for a while. If they are fit to meet standards in terms of hygiene, taste, texture and packaging etc. they are prepared for distribution otherwise, they are discarded (Smit 2003). Dairy products are transferred to distribution centres after going through the quarantine process.

Transport costs of dairy products are high because, they are carried by reefer trucks or vehicles which have cooling systems. Consequently, it is crucial to utilize full capacity of these vehicles. Retailers have a higher level of stocks in many other sectors. However, retailers in dairy products supply chain have relatively lower level of stocks. Because they buy frequently but smaller quantity of dairy products to provide fresh dairy products (Kiambi et al. 2020).

The whole supply chain activities of fermented dairy products explained above can also be summarized in Figure 2 (Malliaroudaki et al. 2022). As seen in Figure 2, milk is transferred to the dairy plant after initial production of raw milk on the farm. In dairy plant milk will be under certain processes to produce end- products.

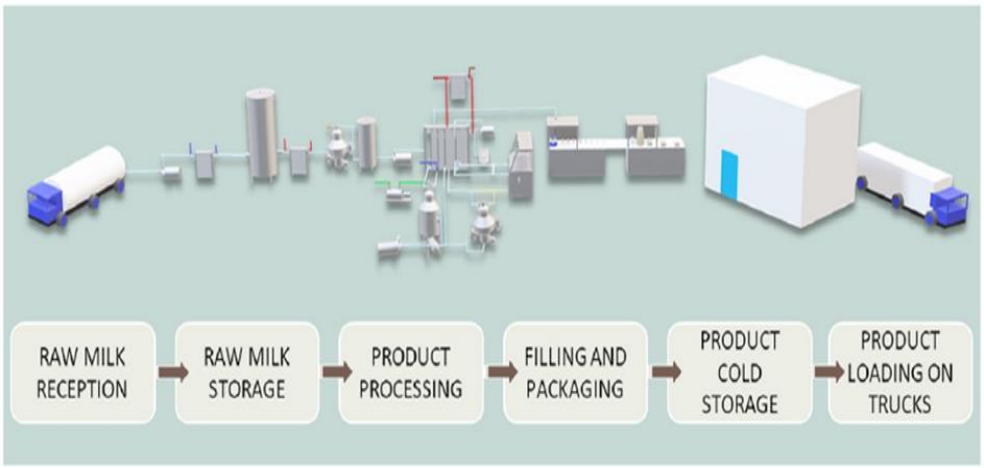

Figure 2- Dairy Production activities taking place in a dairy supply chain for producing fresh dairy products and fermented dairy products including milk, cream, butter, cheese and powdered products. Source: Malliaroudaki et al. (2022) Energy management for a net zero dairy supply chain under climate change. Trends in Food Science & Technology

4. Literature Review

Transport infrastructure is important issue in dairy supply chain because, quality of milk transportation plays an important role (Martinelli et al. 2022). According to the study done by Martinellli et al. (2022) in Brazil by collecting data from 347 dairy farmers, quality of milk transport is one of competitive indicators that effects farmers' competitiveness in the dairy supply chain. In the study condition of main roads as well as secondary roads were chosen as sub-indicators in quality of milk transport in the study.

There are some studies investigating effect of labour on agri-food value chain sustainability, one of them was done by Malanski et al. (2022) which suggests that improving employment as well as working conditions may promote agri-food value chain sustainability. There are also some studies investigating labour productivity in agriculture. For example, according to the result of the study done by Cortignani et al. (2020) suggests that use of temporary labour leads to instability because workers in farmlands are employed only in some, generally short, period of the production cycle. Some studies investigate labour productivity in dairy production. According to one of them done by Sarvana & Padrian (2013) it was concluded that additional workforce decreased labour productivity. However, Hussain et al. (2010) determined that a 1% increase in labour hours increased milk production by 2,15%. Consequently, according to this study, number of blue-collar employees has a positive effect on fermented dairy production capacity at 0.001 significance while the number of white-collar employees does not have a significant effect on the fermented dairy production capacity. In a recent study, Garcia-Covarrubias et al. (2024) have found that additional labour in Ireland has a positive impact on dairy production on farms, particularly amplifying these effects on small and medium-sized farms.

According to some studies done by Tse et al. (2018); Silvi et al. (2021) although food and dairy production are deemed to be low-tech, changing as well as improving new technologies have greater impact on food and dairy production. This will lead to a decrease in labour requirement however increase efficiency. However, Du et al. (2022) reached a conclusion that only a small fraction of farms utilizing milking machineries or robots in milk production process employed less workers after robotic technology. On the other hand, Bewley et al. (2001) reached a conclusion that integration of technology into dairy production increased labour productivity. Frick et al. (2019) determined that innovation activities in food production increased labour production more than in high-tech sectors. Moreover, an increase in population as a result, an increase in demand lead to more increase in employment and production in food production sector compared to other sectors (Tereszczuk & Marczak 2018; Grodach & Martin 2020).

5. Dataset and Model

Dataset related to labour employed in dairy processors and fermented dairy production capacity was obtained from the Union of Chambers and Commodity Exchanges of Turkey (TOBB) where there was a data with regard to production of 13 different fermented dairy products. Additionally, the data related to length of roads (in Km) in 48 cities were obtained from General Directorate for Highways. In this context, information on the production capacity of 2731 dairy processors doing business in 48 cities in Turkey and providing a capacity report was utilized. Because data used in the study consisted of total dairy production capacity as well as qualified and unqualified labour per city, dataset was formed including 227 sub-sectors in 48 cities. Consequently, the dataset used in the study includes the information of total fermented dairy production capacity, the number of employees including engineers, managerial personnel, foremen, technicians, workers working in the fermented dairy production process as well as total length of roads in 48 cities. 5 different labour groups i.e., engineers, managerial personnel, foremen,

technicians as well as workers are broken into two different groups i.e., skilled-educated labour as well as unskilled-uneducated labour as suggested by Acemoğlu (1998); Goldin & Katz (1998) based on "skill biased technical change". This approach suggests that technological change increases efficiency of skilled labour and demand in skill labour however it has an opposite effect for unskilled labour. As mentioned before, production of fermented dairy products that is considered in food sector is in low-tech production process as well as it is labour intensive. However, a need for some specific knowledge in fermenting process lately, increase in technology in food production render skilled labour as important as ever before. White-collar signifies engineers as well as managerial personnel while blue-collar signifies technicians, foremen as well as workers in the study. Here, white-collar symbolizes well-educated employees blue-collar symbolizes uneducated workers as well as foremen, technicians who need some special education and knowledge. Based on the scope of the study explained above roadmap of the study can be formed as in Figure 3.

GLM has been utilized to find out the effect of the length of roads, the number of white-collar as well as blue-collar employees on fermented dairy production capacity. Table 1 provides the necessary information on dependent and independent variables.

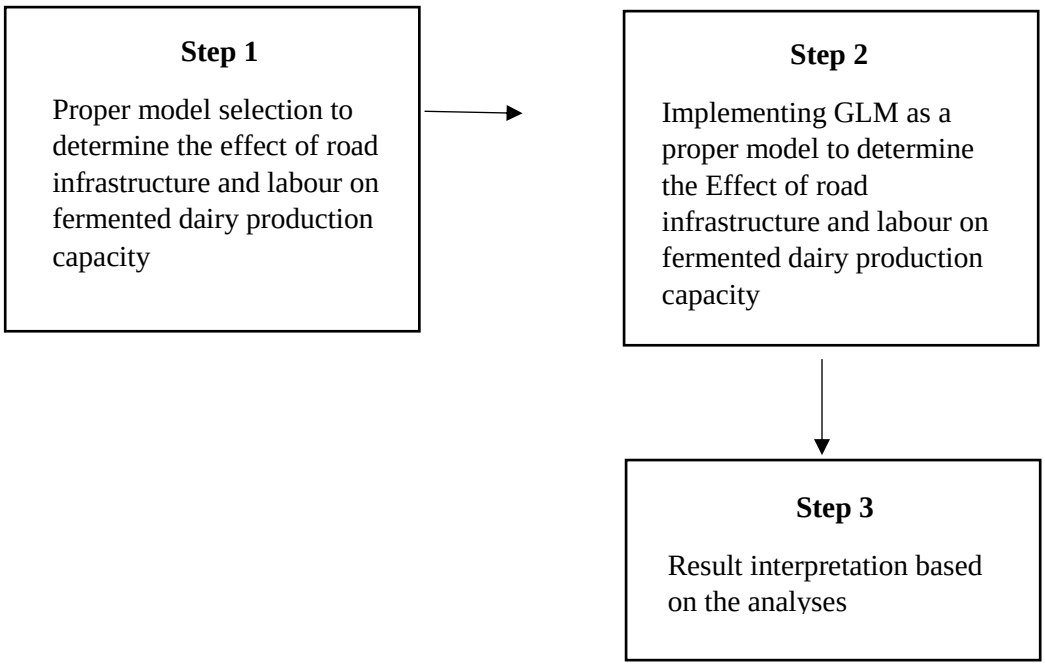

Figure 3- Roadmap of the Study

Table 1- Descriptive Statistics related to Dependent and Independent Variables. Source: Own calculations based on Turkish Union of Chambers and Exchange Commodities and General Directorate of Highways (2022)

Variable	*N*	*Mean*	*Standard Deviation*	*Median*	*Skewness*	*Kurtosis*
Production Capacity (dependent variable)	227	1.16+07	2.66+07	3735520	6.467988	59.17881
White-collar Labor	227	91.22907	155.1436	38	5.617148	51.20763
Blue-collar Labor	227	534.2775	751.7396	260	4.08083	30.66947
Total Road	227	445.2731	330.3021	353	2.222786	8.642645

Values of skewness, kurtosis of production capacity, positive difference between its median and mean state that distribution is not a normal distribution. Dependent variable i.e., production capacity as well as figure of distribution of residuals based on conventional linear regression model is obtained through histogram which are shown in Figure 4.

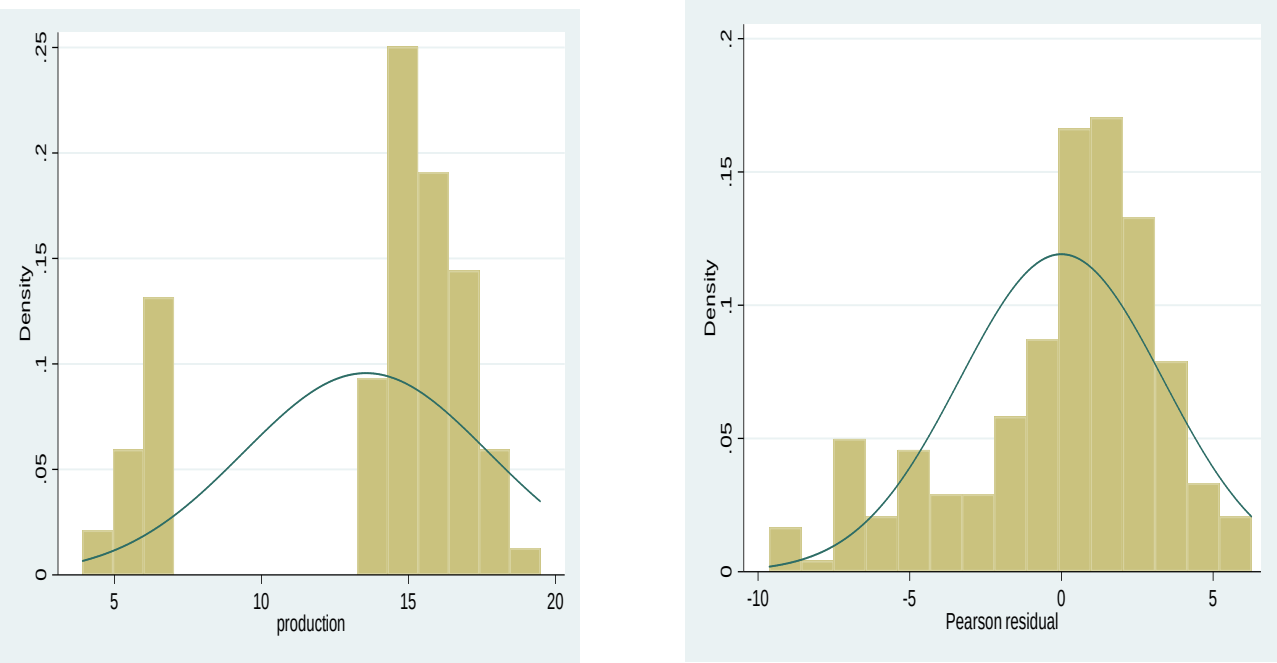

Figure 4- Production Capacity and Histogram of Distribution of Residuals. Source: Own calculations based on Turkish Union of Chambers and Exchange Commodities and General Directorate of Highways

As seen in Figure 4, distribution of production capacity is too left-skewed. This distribution is a contradiction to basic assumption of conventional linear regression model. Consequently, Generalized Linear Models are utilized instead. Generalized Linear Models developed by Nelder & Wedderburn (1972) consist of response variables (dependent variable) as well as non-normal (conditional) distributions through transformation termed as link function.

Generalized Linear Models provides flexibility for two important assumptions of conventional Linear Regression (normality and heteroscedasticity). General Linear Models can be formulated easily by choosing a proper response (probability) distribution and a link function. In this sense, Generalized Linear Models (GLM) provide social scientists with a simplified as well as flexible approach for constructing a statistical model (Wu 2005).

Generalized Linear Model can be defined as;

$$f(y) = c(y, \emptyset) exp\left\{\frac{y\theta - a(\theta)}{\emptyset}\right\},\ g(\mu) = X\beta \qquad (1.3)$$

for exponential distributions based on probability density function.

In Equation (1.3) $g(\mu)$, indicates transformation of mean that represents predicted value of the dependent variable. In this context, GLMs consist of three basic components (Lindsey 2000):

1) *Coincidental Component or "Error Construct":* Y (i 1……..n) μ_i are independent coincidental variables with mean. They share the same distribution with a constant scale parameter from an exponential distribution family.

2) *Linear Component:* This represents linear systematic component. It is indicated by $n = X\beta$

3) *Link Function:* It is the last component of GLM. It fulfils a predictor link function in relation between Mean of i^{th} sample and its linearity. It is indicated by $n = g_i(\mu_i)$.

Priority in constructing GLMs is to determine a proper kind of exponential distribution for a dependent variable as well as determine a proper link function for the determined distribution. When $g(\mu) = \theta$, g is termed as canonical link function. There could be different distributions and link functions based on the structure of a dependent variable.

Gamma and inverse normal distributions are frequently used because of the structure of a positive continuous data corresponding to the dependent variable of the study. Unit and log functions are preferred for link function in general (Fox 2015). Akaike (AIC) and Basian (BIC) information criterions can be used to determine the most proper model for the dataset. This information criterion allows to compare interwoven models to un-nested models. The models might vary by linear predictor, link functions and distribution of response variables (Anderson et al. 2010). The other method of model comparing is coefficient

significance which is obtained by including a variable which is equal to square of linear predictor in the model to predict a dependent variable. If coefficient is significant, it is assumed that there is lack of goodness of fit in the model (Hardin & Hilbe 2007). Consequently, in the study different model predictions are carried out with different link functions for gamma and gaussian distributions. Obtained information criterion as well as information of the coefficient related to square of the dependent variable are exhibited in Table 2.

Table 2- Model Comparison Criterion

Distribution-Link Function	*AIC*	*BIC*	*Square Variable Model*		
			HAT	*HATSQUARE*	*CONS*
Gaussian-identity	**5.285774**	1324.362	2.559229***	**-.0579095***	-10.13846*
Gaussian-log	5.309716	1385.767	70.92451**	-10.97332*	-96.22754**
Gamma-identity	7.210662	**-1187.00**	2.34645***	-.0531617**	-8.117995*
Gamma-log	7.2129	-1186.50	59.36268**	-9.081588*	-78.90173**

***, **, and ***: significant at 1%, 5% and 10% respectively.** Source: Own calculations based on Turkish Union of Chambers and Exchange Commodities and General Directorate of Highways

As can be seen in Table 2, the most suitable model distribution is gaussian (inverse normal) while most suitable link function is unit according to both information criterion as well as square variable models. Furthermore, Pearsan residuals suggested by McCullogh & Nelder (1989) are also reviewed in order to examine measures of goodness of fit in GLMs. According to this view, the most important indicator which shows that the model is properly constructed is the fact that distribution of residuals approaches to normal distribution.

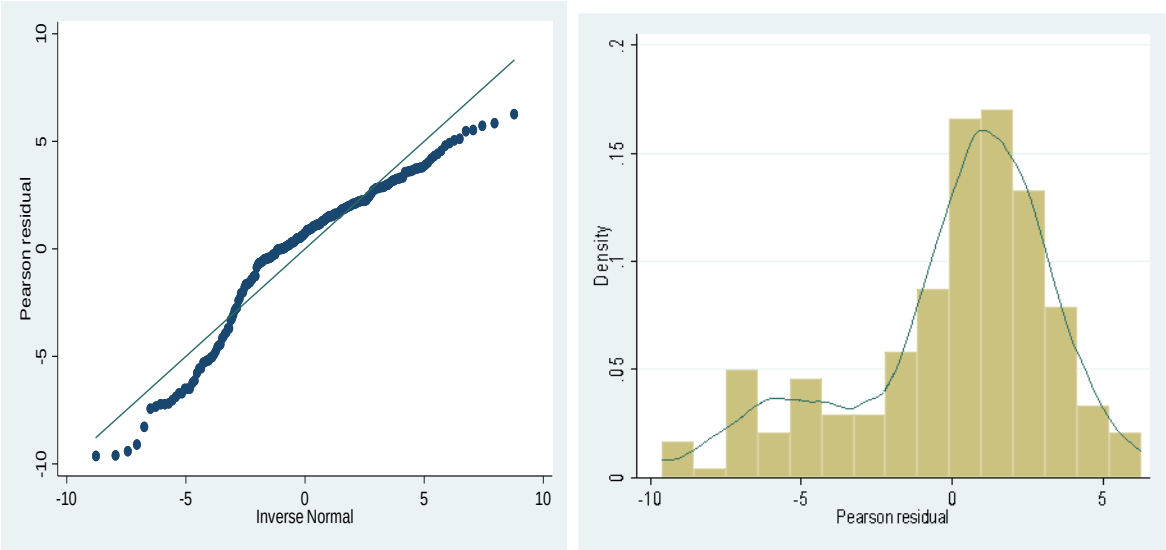

Figure 5- Gaussian distributed Unit Link Function Generalized Linear Model Pearson Residuals. Source: Own calculations based on Turkish Union of Chambers and Exchange Commodities and General Directorate of Highways

It is apparent that distribution has approached to normal distribution when Figure 5 is compared to Figure 4. This provides important evidence that model is constructed properly.

In the result of examining of all these statistics as well as histogram it is concluded that model will be predicted. Unit link function and gaussian (inverse normal) will be utilized for GLM. The results are exhibited in Table 3.

Table 3- Gaussian distributed Unit Link Function Generalized Linear Model Results

Namber of obs.=227	Residual df=223
Scale parameter=11.3638	(1/df) Deviance =11.3638
1/df pearson=11.3638	Deviance= 2534.126332
Pearson = 2534.126332	AIC= 5.2857
Log pseudolikelihood = -595.9352984	
Variance function: V(u) = 1	
Link function: g(u) = u	
Dependent Variable: Production capacity	Coefficient
Variables	
the number of Blue- Collar Employees	1.819683***
	(0.6003369)
the number of White- Collar Employees	0.1529437
	(0.1529437)
Length of Total Roads (km) in cities	0.548256*
	(3203659)
Constant	-0.3486598
	(2.208456)

(i) *, **, and * significant at 1%, 5% and 10% respectively. (ii) The values in bracket are with standard error. (iii) Inverse normal distribution and unit link function are utilized in model prediction.** Source: Own calculations based on Turkish Union of Chambers and Exchange Commodities and General Directorate of Highways

As seen in Table 3, the number of blue-collar employees has a positive effect on fermented dairy production capacity at 0.001 significance while the number of white-collar employees does not have a significant effect on the fermented dairy production capacity on the other hand length of road (in km) in cities where fermented dairy products are produced has a positive effect on the fermented dairy production capacity at 0.10 significance level.

6. Conclusions

According to the results of the study, a unit increase in the number of blue-collar employees leads to 1.82-unit increase in fermented dairy production capacity. This justifies the idea of Liu et al. (2014) which states that labour has a prominent effect on production processes in food production. This result in the study also supports the result of the study done by Hussain et al. (2010) and Garcia-Covarrubias et al. (2024). On the other hand, this result in the study contradicts the idea suggested by Saravana et al. (2013) which is claimed that additional labour in dairy production might decrease efficiency.

Although the data as well as model in the study do not provide information about technology used in fermented dairy production, some interpretation can be made for fermented dairy production which is considered among low-tech sectors. First of all, the result of study related to white-collar employees having no significant impact on fermented dairy production capacity contradicts hypothesis of skill biased technical change. This may stem from two probable situations. First, milk processors located in Turkey that constitute scope of the study might have low level of technology in their fermented dairy production. This might cause white-collar employees to participate in managerial or sale activities rather than production processes.

Secondly, diversity of blue-collar in the sector might cause this. As mentioned before, blue-collar employees consist of foremen, workers as well as technicians. In most cases, foremen and technicians can be required to have a certain level of education. These employees might be deemed as qualified employees. This is in line with mentioned hypothesis as well as the results reached by Bewley et al. (2001) and Frick et al. (2019).

The results related to white as well as blue collar has been interpreted based on two approaches mentioned before in the study. However, a potential future study which includes level of technology use as well as aspects of human capital in firms producing fermented dairy products might reach more comprehensive also clearer conclusions.

The other result of the study is that one-unit increase in length of roads (in km) in cities where fermented dairy production is taking place results in 0.5-unit increase in fermented dairy production capacity. This is an expected result which is line with the related literature. For example, according to Subburaj et al. (2015) the important issue in dairy supply chain is transport infrastructure and condition of roads. According to the study poor transport infrastructure in dairy supply chain was found to be one of the greatest challenges in dairy business. In their study Kiambi et al. (2020) reached similar results. According to the study, one of the biggest challenges faced by large dairy processors was poor roads and public infrastructure. Authors suggested that this might led to risk of milk spoilage. Consequently, when related literature taken into consideration, the result of this study which emphasizes the effect of roads on fermented production capacity is rightfully sound.

Transport cost, energy use, water use, warehousing cost and inventory carrying cost in the fermented products supple chain dairy are also important issues. For example, Malliaroudaki et al. (2022) emphasized energy use in dairy production. They

suggested some mitigation strategies for energy use. Talukder et al. (2021) listed inventory carrying cost warehousing cost, distribution cost finally water consumption as probable indicators of lean, agile and sustainable supply chains in dairy business. Especially, cold chain in logistics activities of dairy product is very vital because, raw milk should be stored in a cool condition both in the phases of milk collecting and dairy production (Martinelli et al.2022). Without a proper cold chain milk will certainly spoil. There are some studies done by Tostivint et al. (2017); Kiambi et al. (2020); Subburaj et al. (2015) which emphasize the importance of cold chain in dairy supply chain. As mentioned above although cold chain, transport cost, energy use, water use, warehousing cost, inventory carrying cost are important dependent variables they are not included in the study because, database in Turkey lacks proper information of these important components in the dairy supply chain. Consequently, in the future if proper data is reached consisting of information on these aspects the dairy supply chain in Turkey the effect of these elements on fermented dairy production capacity can also be investigated.

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References

Acemoglu D (1998). Why do new technologies complement skills? Directed technical change and wage inequality. Quarterly Journal of Economics 4(113): 1055-1089. Available at https://doi.org/10.1162/003355398555838 (accessed January 9, 2023).

Akin A & Cevger Y (2019). Analysis of factors affecting production costs and profitability of milk and dairy products in Turkey. Food Science and Technology 39: 781-787. Available at https://doi.org/10.1590/fst.28818 (accessed February 28, 2023).

Anderson C J, Verkuilen J & Johnson T (2010). Applied Generalized Linear Mixed Models: Continuous and Discrete Data. Springer, New York, USA. pp. 170-172

Bewley J, Palmer R W & Jackson-Smith D B (2001). Modelling milk production and labor efficiency in modernized Wisconsin dairy herds. *Journal of Dairy Science* 84(3): 705-716. Available at https://doi.org/10.3168/jds.S0022-0302(01)74525-0 (accessed January 27, 2023).

Cortignani R, Carulli G, Dono G (2020). COVID-19 and labour in agriculture: Economic and productive impacts in an agricultural area of the Mediterranean. *Italian Journal of Agronomy* 15(2): 172-181. Available at https://doi.org/10.4081/ija.2020.1653 (accessed May 4. 2023).

Dani S (2015). Food Supply Chain Management and Logistics: From Farm to Fork. Kogan Page Publishers, Great Britain pp. 13.6

Du X Tejeda, H Yang Z & Lu L (2022). A general-equilibrium model of labor-saving technology adoption: Theory and evidences from robotic milking systems in Idaho. Sustainability 14(7683): 1-17. Available at https://doi.org/10.3390/su14137683 (accessed December 28, 2022).

Eurostat (2017). Available from https://ec.europa.eu/eurostat (accessed: 15.January.2023).

Fassio L H, Reis R. P & Geraldo L G (2006).Technical and economical effectiveness of milk production from Minas Gerais state, Brazil. Ciência e Agrotecnologia 30: 1154-1161. Available at https://doi.org/10.1590/S1413-70542006000600018 (accessed March 3, 2023).

Fox J (2015). Applied Regression Analysis and Generalized Linear Models, Sage Publications, California, USA pp. 103-105

Frick F, Jantke C & Sauer J (2019). Innovation and productivity in the food vs. the high-tech manufacturing sector. Economics of Innovation and New Technology 28(7): 674-694. Available at https://doi.org/10.1080/10438599.2018.1557405 (accessed March 1, 2023).

García-Burgos M, Moreno-Fernández J, Alférez M J, Díaz-Castro J & López-Aliaga I (2020). New perspectives in fermented dairy products and their health relevance. *Journal of Functional Foods* 72: 1-11. Available at https://doi.org/10.1016/j.jff.2020.104059 (accessed February 28, 2023).

Garcia-Covarrubias L, Läpple D, Dillon E & Thorne F (2024). The role of hired labour on technical efficiency in an expanding dairy sector: The case of Ireland. *Australian Journal of Agricultural and Resource Economics*. Available at https://doi.org/10.1111/1467-8489.12553 (accessed May 6, 2024).

Goldin C & Katz L F (1998). The origins of technology-skill complementarity, *Quarterly Journal of Economics* 113(3): 693-732. Available at https://doi.org/10.1162/003355398555720 (accessed March 1, 2023).

Grodach C & Martin D (2021). Zoning in on urban manufacturing: industry location and change among low-tech, high-touch industries in Melbourne, Australia. Urban Geography 42(4): 458-480. Available at https://doi.org/10.1080/02723638.2020.1723329 (accessed March 1, 2023).

Hardin J W & Hilbe J M (2007). Generalized Linear Models and Extensions, Stata Press, Texas, USA. 108 pp

Hussain M, Ghafoor A & Saboor A (2010). Factors affecting milk production in buffaloes: a case study. Pakistan Vet. J 30(2): 115-117. Available at www.pvj.com.pk (accessed December 27, 2022).

Janssen B (2013). Herd management: labor strategies in local food production. Anthropology of Work Review 34(2): 68-79. Available at https://doi.org/10.1111/awr.12011 (accessed February 18, 2023).

Kiambi S, Onono J O, Kang'ethe E, Aboge G O, Murungi M K, Muinde P & Alarcon P (2020). Investigation of the governance structure of the Nairobi dairy value chain and its influence on food safety. Preventive Veterinary Medicine 179: 1-15. Available at https://doi.org/10.1016/j.prevetmed.2020.105009 (accessed January 28, 2023).

Krampe C & Fridman A (2022). Oatly, a serious 'problem'for the dairy industry? A case study. International Food and Agribusiness Management Review 25(1): 157-171. Available at https://doi.org/10.22434/IFAMR2021.0058 (accessed June 21, 2023).

Kumari B, Chandel B S & Lal P (2020). Economic analysis of milk production in eastern region of India. *Indian Journal of Dairy Science* 73(5). Available at https://doi.org/10.33785/IJDS.2020.v73i02.010 (accessed December 28, 2022).

Leonardo W J, van de Ven G W, Udo H, Kanellopoulos A, Sitoe A & Giller K E (2015). Labour not land constrains agricultural production and food self-sufficiency in maize-based smallholder farming systems in Mozambique. Food Security 7(4): 857-874. Available at https://doi.org/10.1007/s12571-015-0480-7 (accessed February 5, 2023).

Lindsey J K (2000). Applying Generalized Linear Models. Springer Science & Business Media, New York, USA, 52 pp

Liu C, Li Y & Shen W (2014). Integrated manufacturing process planning and control based on intelligent agents and multi-dimension features. *The International Journal of Advanced Manufacturing Technology* 75: 1457-1471. Available at https://doi.org/10.1007/s00170-014-6246-0 (accessed March 2, 2023).

Malanski P D, Schiavi S, Dedieu B & Damasceno J C (2022). Labor in agrifood value chains: a scientometric review from Scopus. International Food and Agribusiness Management Review 25(3): 449-468. Available at https://doi.org/10.22434/IFAMR2021.0066 (accessed July 1, 2023).

Martinelli R R, Damasceno J C, de Brito M M, da Costa V D V, Lima P G L & Bánkuti F I (2022). Horizontal collaborations and the competitiveness of dairy farmers in Brazil. *Journal of Co-operative Organization and Management* 10(2): 1-11. Available at https://doi.org/10.1016/j.jcom.2022.100183 (accessed February 3, 2023).

McCullogh P & Nelder J A (1989). Binary Data. In Generalized Linear Models. Springer, US. 99 pp

Nahar A, Mila F A, Culas R J & Amin M. R (2022). Assessing the factors and constraints for value chain development of dairy food products in Bangladesh. Heliyon 8(10): 1-8. Available at https://doi.org/10.1016/j.heliyon.2022.e10787 (accessed February 28, 2023).

Nelder J A & Wedderburn R W M (1972). Generalized linear models. *Journal of the Royal Statistical Society* 135: 370–384. Available at https://doi.org/10.2307/2344614 (accessed December 29, 2022).

Nmadu J N & Akinola A (2015). Farm labour supply and utilization for food crop production in Nigeria. In Proceedings of the 2nd International Conference on Education and Social Sciences (INTCESS15), Istanbul, Turkey, February, 2-4, 2015 pp.311-320

Ojo S O (2004). Improving labour productivity and technical efficiency in food crop production: A panacea for poverty reduction in Nigeria. *Journal of Food Agriculture and Environment* 2: 227-231. Available at www.world-food.net (accessed January 3, 2023).

Rutledge Z & Mérel P, (2022). Farm labor supply and fruit and vegetable production. *American Journal of Agricultural Economics* 105(2): 644-673. Available at https://doi.org/10.1111/ajae.12332 (accessed January 8, 2023).

Saravana Pandian A, Selvakumar K N, Prabu M & Ganeshkumar B (2013). Assessing the productivity of resources in milk production in Tamil Nadu-an econometric analysis. *Indian Journal of Animal Research* 47(3): 541-559. Available at https://www.arccjournals.com/ (accessed February 14, 2023).

Sargent, J & Matthews L (2008). Capital intensity, technology intensity, and skill development in post China/WTO maquiladoras. World Development 36(4): 541-559. Available at https://doi.org/10.1016/j.worlddev.2007.04.015 (accessed March 1, 2023).

Shafiee Z & Sharifi G (2017). Comparing the effect of resistance, aerobic, and concurrent exercise program on the level of resistin and high reactive protein c of overweight and obese women. Int Arch Health Sci, 4: 1-6. Available at DOI: 10.4103/iahs.iahs_4_17 (accessed January 8, 2023).

Silvi R, Pereira L G R, Paiva, C A V, Tomich, T R, Teixeira V A, Sacramento J P & Dórea, J R R (2021).Adoption of precision technologies by Brazilian dairy farms: The farmer's perception. Animals 11(3488): 1-16. Available at https://doi.org/10.3390/ani11123488 (accessed January 8, 2023).

Smit, G (2003). Dairy Processing: Improving Quality. Cambridge, England, Woodhead Publishing in Food Science and Technology 545: 103

Střeleček F, Zdeněk R & Lososová J (2007). Influence of farm milk prices in the EU 25 on profitability and production volume indicators. Agricultural Economics–Czech 53: 545-557. Available at DOI: 10.17221/1224-AGRICECON (accessed February 9, 2023).

Subburaj M, Babu T R & Subramonian B S (2015). A study on strengthening the operational efficiency of dairy supply Chain in Tamilnadu, India. Procedia-Social and Behavioral Sciences 189: 285-291. Available at https://doi.org/10.1016/j.sbspro.2015.03.224 (accessed January 10, 2023).

Talukder B, Agnusdei G P, Hipel K W & Dubé L (2021). Multi-indicator supply chain management framework for food convergent innovation in the dairy business. Sustainable Futures 3: 1-14. Available at https://doi.org/10.1016/j.sftr.2021.100045 (accessed January 18, 2023).

Tereszczuk M & Mroczek R (2018). Labor productivity and concentration of food production in the Polish food industry against the EU-28. Zeszyty Naukowe Szkoły Głównej Gospodarstwa Wiejskiego w Warszawie-Problemy Rolnictwa Światowego 18(1): 299-308. Available at 10.22630/PRS.2018.18.1.27 (accessed January 21, 2023).

Tostivint C, de Veron S, Jan O, Lanctuit H, Hutton Z V & Loubière M (2017). Measuring food waste in a dairy supply chain in Pakistan. *Journal of Cleaner Production* 145: 221-231. Available https://doi.org/10.1016/j.jclepro.2016.12.081 (accessed February 18, 2023).

Tse C, Barkema H W, DeVries T J, Rushen J & Pajor E (2018). Impact of automatic milking systems on dairy cattle producers' reports of milking labour management, milk production and milk quality. Animal 12(12): 2649-2656. Available at https://doi.org/10.1017/S1751731118000654 (accessed March 3, 2023).

Zhang W (2005). Generalized linear models in family studies, *Journal of Marriage and Family* 67(4): 789-1101. Available at https://doi.org/10.1111/j.1741-3737.2005.00192.x (accessed February 15, 2023).

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Non-destructive Weight Prediction Model of Spherical Fruits and Vegetables using U-Net Image Segmentation and Machine Learning Methods

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ABSTRACT
Artificial intelligence has become increasingly prominent in agriculture and other fields. Prediction of body weight in animals and plants has been done by humans using many different methods and observations from the past to the present. Although there has been extensive research on predicting the live body weight of animals, weight prediction of vegetables and fruits is not widely. As spherical or round-shaped fruits and vegetables are sold by weighing in the fields, markets and greengrocers, it is important to make weight predictions. Based on this, a model was developed to predict the weight of fruits and vegetables such as watermelons, melons, apples, oranges and tomatoes with the data obtained from their images. The fruit and vegetable weights were predicted by regression models using data obtained from images segmented by the U-Net architecture. Machine learning models such as Multi-Layer Perceptron (MLP), Random Forest (RF), Decision Trees (DT), Support Vector Machines (SVM), Linear and Stochastic Gradient Descent (SGD) regression models were used for weight predictions. The most effective regression models are the RF and DT models. For regression training, the best success rates were calculated as 0.9112 for watermelon, 0.9944 for apple, 0.9989 for tomato and 0.9996 for orange. In addition, the results were evaluated by comparing them to the studies of weight prediction. The weight prediction model will help to sell round-shaped fruits and vegetables in the fields, markets and gardens using the weight predictions from the images. It is also a guideline for studies that follow the growth of fruit and vegetables according to their weight.

Keywords: Artificial intelligence techniques, image segmentation, Fruits and vegetables, Weight prediction

1. Introduction

The development of a country's economy is significantly reliant on the progress of its agricultural sector, which serves as a crucial source of employment for the poor (Gondchawar & Kavitkar 2016). The demand for innovative approaches is increasing day by day in order to prevent the decrease in yield caused by problems such as climate change, food quality and safety, and post-harvest deterioration in the agricultural industry (Pathan et al. 2020). The implementation of smart technologies in agriculture has led to increased agricultural productivity and opened up new employment opportunities while reducing the need for manual labor (Barbole et al. 2021). Smart agriculture utilizes information and communication technologies to enhance the productivity and quality of agricultural produce. Precision agriculture is a field within smart agriculture that is part of the third agricultural revolution. This approach offers a more objective and precise means of analysis (O'grady et al. 2019).

Smart agriculture is a system incorporating applications that leverage science, innovation, and space technologies. The Internet of Things (IoT) is used for measuring soil quality, moisture levels and weather conditions (Friha et al. 2021). Additionally, various technologies including cloud communication, robotics, wireless sensor technologies, Unmanned Aerial Vehicles (UAVs), mobile devices, and Global Positioning System (GPS) are being used. The recent technological advancements have also led to an increase in Artificial Intelligence (AI) research (Kassim 2020). AI tools, such as Artificial Neural Networks (ANN), Fuzzy Logic used by Cornelis et al. (2006), Genetic Algorithms, Machine Learning used by Mahesh (2020) and Deep Learning used by Fernandes et al. (2020) are being used in areas such as agricultural production, medical science, health services, speech recognition, robotics and disease detection. When dealing with limited data, regression and classification can be performed using machine learning models such as Partial Least Squares (PLS) as used by Yan et al. (2019), ANN as used by Akkol et al. (2017), random forests as used by Babajide et al. (2020), and Support Vector Machines (SVM) as used by Faisal et al. (2020). Similarly, deep learning models such as Convolutional Neural Networks (CNN) used by Alzubaidi et al. (2021), Recurrent Neural Networks (RNN) used by Xiao & Zhou (2020), and Long Short-Term Memory (LSTM) used by Yu et al. (2019) are utilized in the big data applications. The most prevalent architectures employed for image segmentation include U-Net, Seg-Net, Mask R-CNN, FCN, and Deeplabv3, among others (Li et al. 2017; Rudenko et al. 2020). U-Net-based models,

which are successful in creating accurate mappings and processing small datasets, have been integrated into agriculture to extract multi-scale features for the segmentation of images with complex backgrounds. This approach has been successfully applied to fruit segmentation, resulting in more efficient object detection (Chicchón Apaza et al. 2020).

Studies on live weight estimations in animals and vegetables and fruits have been increasing recently compared to previous years. In the first studies, predictions were made using the data obtained from the body measurements of the animals, while recently, because animals are discomforted from contact data are created using the body measurements of the animals from the images using computer vision. With the development of artificial intelligence, the weight predictions are made by using both images and data obtained from sensors that monitor the development of plants in order to follow the development of animals and vegetables-fruits. Computer vision-based segmentation techniques are investigated to identify defective areas in fruits such as apples and bananas, and vegetables such as potatoes, tomatoes, and cucumbers (Rozario et al. 2016). 2D, 3D, and infrared cameras, computer image processing technologies, machine learning and deep learning algorithms are used for weight prediction models with complex levels (Ozkaya 2013). Data generation in these models is by extraction and selection of features, image selection, image segmentation, and digital images. Deep learning methods are more advantageous compared to traditional methods due to the complexity of the backgrounds and the presence of multiple objects in the animal images used for weight prediction.

Bargoti & Underwood (2024) used Watershed Segmentation (WS) and Circular Hough Transform (CHT) algorithms in the CNN and MLP-based apple detection study. They successfully identified the image of apples situated in close proximity to the apple image in the tree, which was obscured by leaves and branches. Similarly, Kang & Chen (2020) developed the Dual Attentive Fully Convolutional Siamese Networks (DasNet-v2) algorithm based on deep neural networks for visualizing the environment in which the apples in the tree are located. The apples in the tree were detected and segmented. Furthermore, Rudenko et al. (2020) concluded that segmentation success may be diminished when confronted with intricate images or a multitude of products within the same image. Naroui Rad et al. (2017) employed U-Net architectures, which have proven effective in image segmentation, to obtain data by proportioning the sizes of the products in the image.

In order to obtain new data, Kamiwaki & Fukuda (2024) calculated the volume, color and shape information of radish using 3D image analysis, while Jeong et al. (2024) measured the width and height of strawberries using a computer vision technique and a Light Detection and Ranging (LiDAR) sensor system. Duc et al. (2023) employed a digital image-based system to measure dimensions such as area, perimeter, length and width for soya beans. Xu et al. (2024), on the other hand, calculated the volumes of sweet potatoes with full surface imaging using a LiDAR sensor and a 3D machine vision system. In order to obtain new data for weight estimation, image-based systems such as digital imaging systems, LiDAR sensor systems, cameras, image processing, computer vision, as well as utilized agronomic and phenological factors of crops. Similarly, they are used in methods such as calculating the volume by immersion in water. Teoh & Syaifudin (2007) employed data comprising parameters such as chakan mango area, mango and plant height, and the number of crops in the image.

Xu et al. (2020) estimated the lowest cotton boll weight with a success rate of 81.70%. Kamiwaki & Fukuda (2024) achieved an accuracy rate of 95% in weight estimation for radishes using a RF model, which incorporated volume, color and shape information. Jeong et al. (2024) employed a camera and LiDAR sensor system to measure the size of strawberries, achieving a success rate of 95% with the help of a High-Resolution Networks (HRNet) neural network. Duc et al. (2023) achieved 98% accuracy with an RF model using area, perimeter, length and width measurements. Lee (2023) achieved an accuracy of 99.81% in predicting the weight of apples, bananas and oranges using the CNN model. Huynh et al. (2020) reported a success rate of 96.7% in estimating the weight of cucumbers using data obtained from images of carrots and cucumbers. Niyalala et al. (2019) achieved a 96.94% success rate with the Radial Basis Function (RBF)-SVM model by extracting features from deep images for the mass and volume prediction of cherry tomatoes. In a different study, Ying-Kai et al. (2023) employed an ANN model to predict weights of dragon fruit, utilizing new data such as pixel area, major and minor axis pixel length, obtained following the removal of noise and segmentation from the image using machine vision.

The weight of a single boll is considered an important criterion in determining the yield and quality of cotton. The weight of a cotton boll was estimated from multi-temporal high-resolution visible light remote sensing images acquired by a UAV. In this model, Fully Convolutional Networks (FNN) were used to detect bolls at the opening and extracting stages. Correlation analysis was performed by extracting Visible Band Difference Vegetation Index (VDVI) of during flowering, boll development and opening stages and the RGB mean values. The best results were obtained with least squares linear regression with R^2= 0.8162 and Back Propagation (BP) neural networks with R^2= 0.8170 (Xu et al. 2020). The weight estimation of the eggplant, data on agronomic and phenological factors such as plant height, number of fruits per plant, ratio of fruit length to fruit width, total yield and time to flowering were achieved using in the ANN. An accuracy of 93% was obtained using these parameters (Naroui Rad et al. 2017). Similarly, the weight estimation of melon is utilized a data set of phenological traits, including plant and fruit length, fruit width, number of fruits per plant, days to flowering, days to maturity, days to fruit formation, fruit cavity diameter, and fruit flesh diameter. RF and ANN were employed to predict the final fruit weight of melon, resulting in an accuracy of 88% with ANN (Rad et al. 2015). An ANN model was utilized to estimate the biomass weight of the Maccauba palm. The results were then compared to those obtained from a multiple-regression model. The success rate for dry weight predictions was 98%, while predictions for oil content decreased to 90% (Castro et al. 2017). To estimate the weight of the chokanan mango using image

processing and analysis methods, the pixels of the area covered by the mango in the image were calculated, and the relationship between the mango pixels in the image and its actual weight was analyzed using the statistical regression method. The correlation coefficient of the mango pixels was calculated as 0.9769 (Teoh & Siyaifudin 2007). Furthermore, in studies estimating the weights of adult patients presenting to emergency departments, data were generated by measuring mid-arm length and knee length. The correlation coefficient between the estimated weights of adult patients and actual weights was calculated as 0.89 using the intraclass correlation coefficient. The correlation coefficient between the actual weights and estimates from doctors and nurses was 0.85 and 0.78, respectively (Lin et al. 2009). The age-based weight estimation of Korean children was also performed. The formula used in the study resulted in a success rate of 0.952 (Park et al. 2012).

The objective of this study is to predict the weight of round-shaped fruits and vegetables, drawing inspiration from previous research on live weight prediction in animals. The live body weights of animals are estimated by measuring certain body dimensions. Similarly, machine learning models can predict the weight of vegetables and fruits by analyzing data obtained from their images and using certain criteria. As in the case of animals, the weight estimation of vegetables and fruits without any damage to the product provides convenience in the sale of round-shaped vegetables and fruits in the field, grocery stores and markets where weighing is not possible. Thus, it creates advantageous situations for both producers and consumers by providing convenience in making single or wholesale sales. Simultaneously, estimating the weight of products without handling or damaging them prevents the spread of diseases caused by touching during weighing. This method will help consumer's select rotten or diseased vegetables and fruits because they are lighter than ripe products. It is also a guideline for studies that follow the growth of fruit and vegetables according to their weight.

2. Material and Methods

Figure 1 shows a flow chart of the model developed to predict the weight of round or spherical fruits and vegetables such as watermelons, apples, oranges and tomatoes sold in markets. Precision weighing was used to measure the weight of selected vegetables and fruits. To take pictures of the fruit and vegetables, a device with two arms at different heights was designed and mobile phones were placed on the arms and the pictures were taken at the same distance. Masks were created for the images selected for the training dataset in the segmentation of the images using the U-net architecture. In the segmentation images obtained as the result of U-Net, the pixels containing vegetables and fruits were colored white and the other pixels were black. Furthermore, the area comprising the white pixels from the segmented images was enclosed in a rectangle. New data was obtained by calculating the ratio of white pixels to all pixels and the ratio of the width and height of the rectangle to the width and height of the image. New data were utilized in regression models of machine learning for weight prediction.

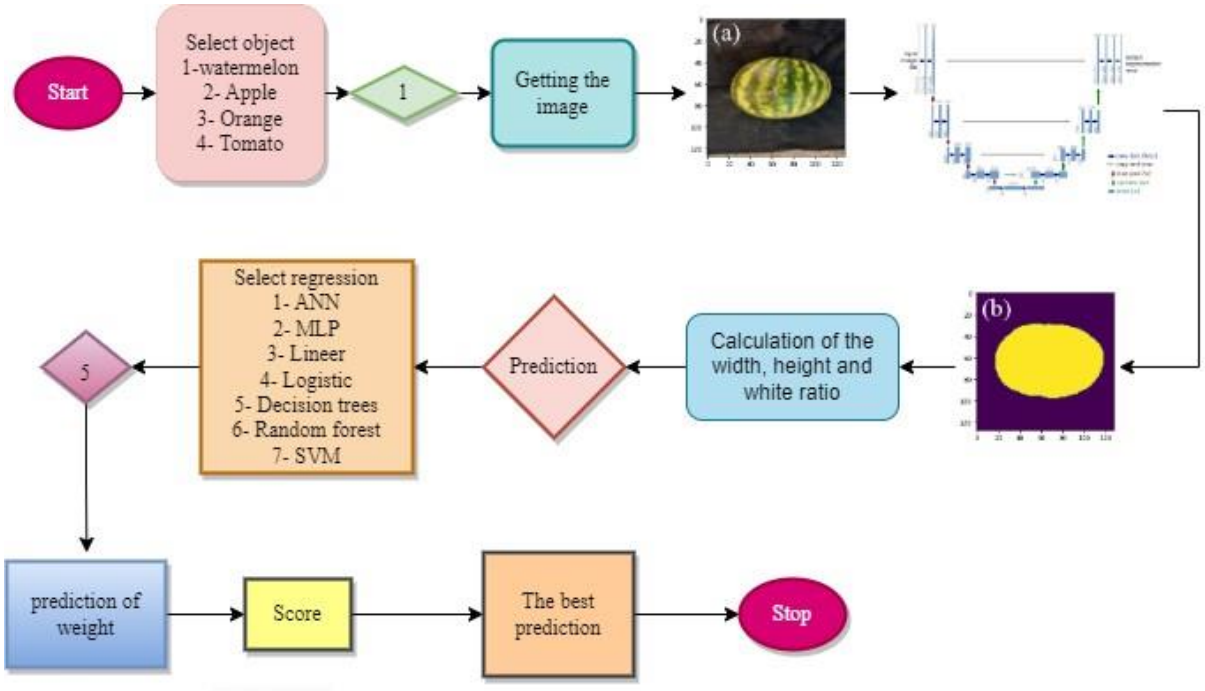

Figure 1- Flow chart of the study

To acquire the fruits and vegetables images, the procedures shown in Figure 2 were followed. Watermelons, apples, oranges, and tomatoes were obtained and weighed with the seller's permission from grocery stores and markets to generate data, as shown in Figure 3, and then images were taken at the same height using a mobile phone placed on the apparatus. The apparatus is designed with two arms and a flat white base on the lower tray. The high arm is designed for taking images of large fruits and vegetables, such as watermelon and melon, and the low arm is designed for taking images of small fruits and vegetables, such

as apples, oranges, and tomatoes. The study analyzed a total of 5000 images from 600 watermelons, 2360 images from 472 tomatoes, 4417 images from 564 apples and 2651 images from 528 tangerines. In the segmentation process with U-Net, 60 images and 60 masks were utilized as the training data, with 40 images employed as the test data. Furthermore, 80% of the data was allocated for training, with the remaining 20% reserved for testing in regression models.

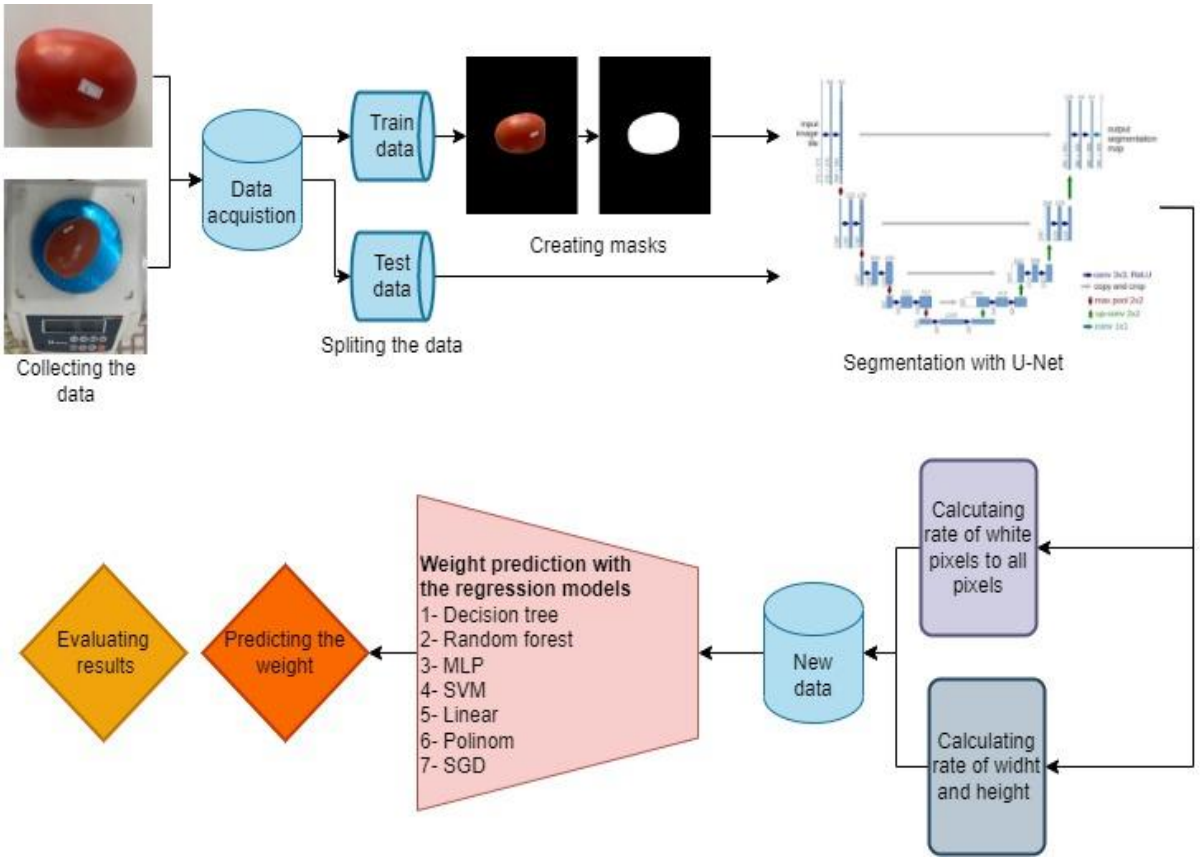

Figure 2- Processes of data acquisition and prediction

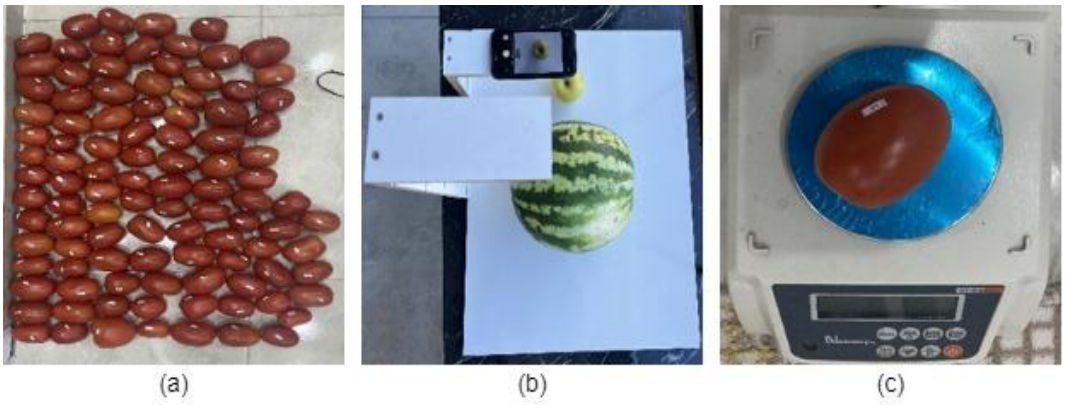

Figure 3- Fruits and vegetables a) tomatoes b) taking the image c) weighing the tomato

2.1. Segmentation of watermelon images with U-Net

Image segmentation is defined as semantic segmentation, which classifies each pixel with semantic labels, sample segmentation, which is based on the segmentation of each object separately, and panoptic segmentation, which combines both segmentations. Semantic segmentation plays a significant role in methods that can divide the image into semantically different objects or parts, which is one of the difficulties in computer vision (Guo et al. 2018). Sample segmentation, on the other hand, solves the object detection problem along with semantic segmentation by assigning labels to different samples of each class. When evaluated for accuracy, the U-Net architecture surpasses traditional segmentation methods. This is specifically important for segmentation methods based on deep CNN (Zhou & Yang 2019).

2.2. Creating a mask

Some of the images were selected for segmentation. Datasets were separated as test and training data in the segmentation with the U-Net architecture. When crafting the image masks utilized for the train data, the background of the image was first erased and the masks were created by coloring the pixels covered by vegetables and fruits as white and the other pixels as black, as shown in Figure 4. The image segmentation was performed using the U-Net architecture, which yields good results with a small number of images shown in Figure 5. The segmentation process was carried out using 100 images, masks of these images and 40 images for testing purposes.

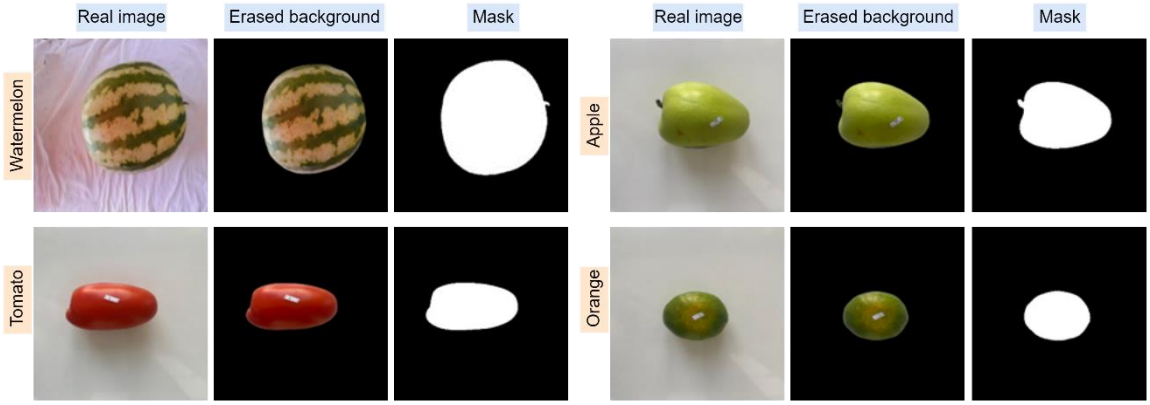

Figure 4- Creating the masks

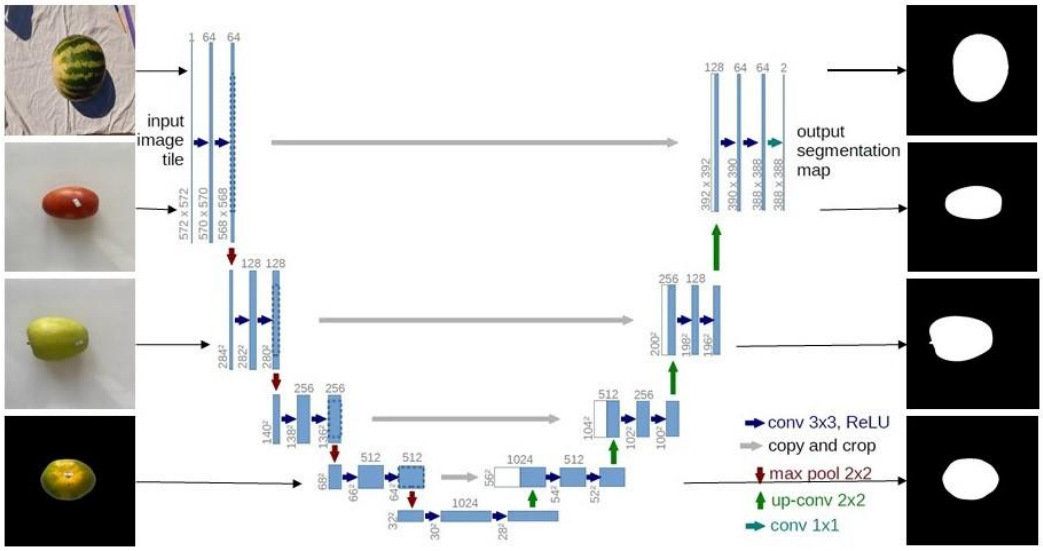

Figure 5- U-Net architecture used in segmentation

2.3. Regression models

The Simple Linear Regression (SLR) is a linear relationship between the independent variable x and the dependent variable y. The line can be accurately described by its y-intercept and slope values. The slope measures the strength of the relationship, while the y-intercept represents the initial position of the regression line (Bangdiwala 2018). The SVM employs a regression model to draw both linear and non-linear lines while maximizing the inclusion of data points. These lines, also known as support vector points, are an essential feature of the model (Wu et al. 2004). In the DT regression model, a random number of nodes and branches at the nodes is used to divide the input data into leaves and branches with consideration for a certain function during training. This enables the regression process to be executed with precision and accuracy (Pekel 2020). The RF is a model produced by training each decision tree on multiple decision trees with different observational data. It is a combination of independent sampling of each tree and making predictions based on the values of the randomly distributed vector of trees with the same distribution. Due to these features, it is applicable to both classification and regression analyses (Breiman 2001). The MLP and ANN are models inspired by the human nerve cell used in fields such as pattern classification, function approach, and dynamic systems. They are based on an information system that multiplies weights on parallel lines connected to all hidden layers of the input layer information, which then passes through the functions used in the hidden layers (Han & Qiao 2013).

2.4. Evaluation criteria

The Mean Squared Error (MSE) is computed as the square of the distance between the actual value and the predicted value (Eq. 1). The Mean Absolute Error (MAE) is a metric that calculates the absolute difference between the actual value and the predicted value (Eq. 2). The Root Mean Squared Error (RMSE) is calculated as the square root of the MSE (Eq. 3). The R^2 is a statistical measure that calculates the degree of closeness between the actual values and the regression line (Eq. 4).

$$MSE = \frac{1}{n}\sum_{i=1}^{n}\left(Y_i - \hat{Y}_i\right)^2 \quad (1)$$

$$MAE = \frac{1}{n}\sum_{i=1}^{n}\left|Y_i - \hat{Y}_i\right| \quad (2)$$

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(Y_i - \hat{Y}_i\right)^2} \quad (3)$$

$$R^2 = 1 - \frac{\frac{1}{n}\sum_{i=1}^{n}(Y_i - \hat{Y}_i)^2}{\frac{1}{n}\sum_{i=1}^{n}|Y_i - \hat{Y}_i|} \quad (4)$$

3. Results

3.1. U-Net results

The results of the U-Net segmentation used in this study are shown in Figure 6. A good result of 0.9961 was obtained by using 100 images with their masks. While the accuracy of the training rose from 0.80 to 0.9961 when 100 epochs were employed, not much of an increase was observed after about 50 epochs. Segmentation images were generated using the values acquired during the training process, as shown in Figure 7.

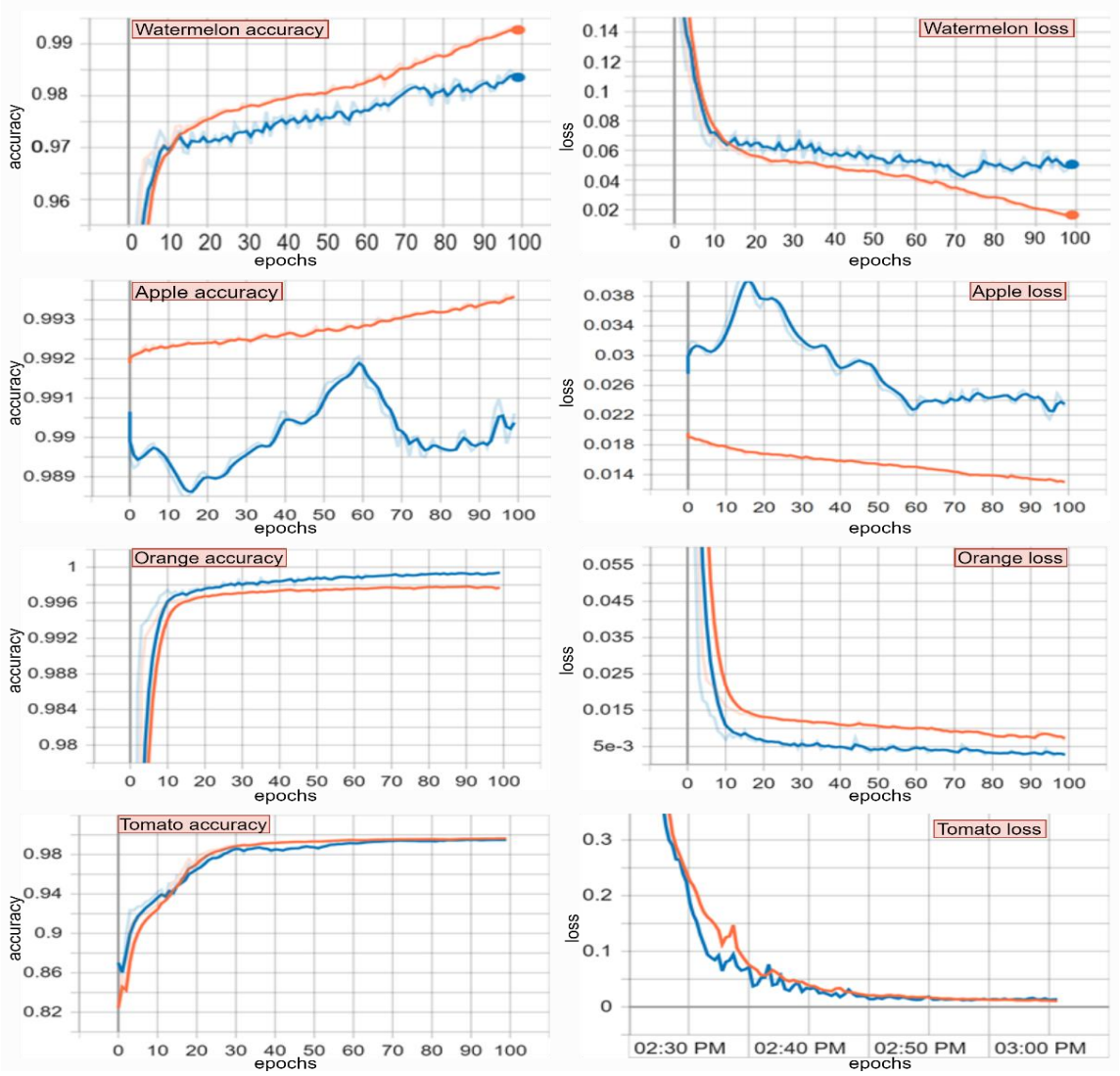

Figure 6- Results of the U-Net train and validation

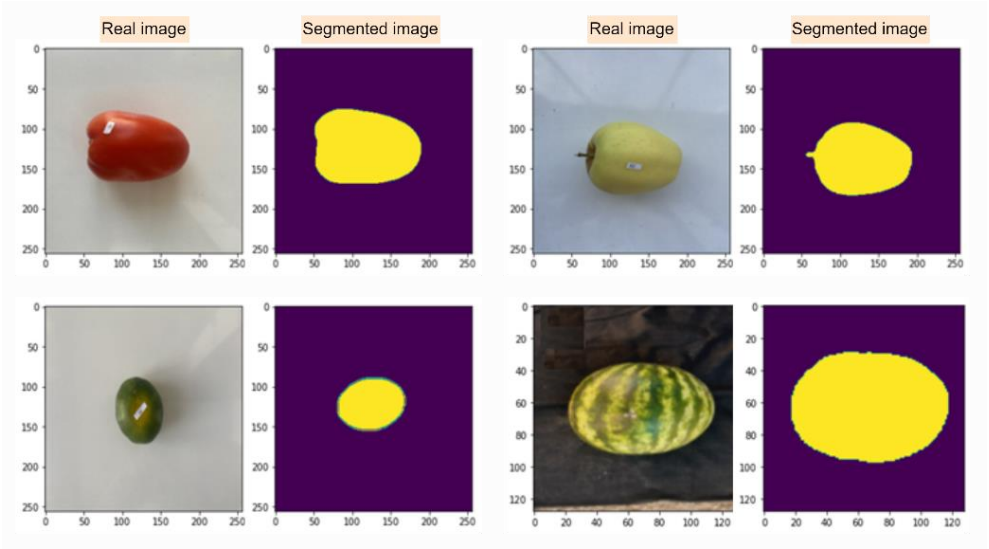

Figure 7- Results of the U-Net segmentation

3.2. Generating data from segmentation images

New data was generated by calculating the ratio of the pixel number of the white in the segmented watermelon images to the total pixel number of each image. Furthermore, by drawing a rectangle over the image shown in Figure 8 that includes the white area, the width rate is calculated as the ratio of the width of the rectangle to the width of the image, and the height rate is calculated as the height of the rectangle to the height of the image. Table 2 presents some of the new data calculated for watermelon. Similarly, these ratios calculated for the watermelon were also calculated for the apple, orange, and tomato.

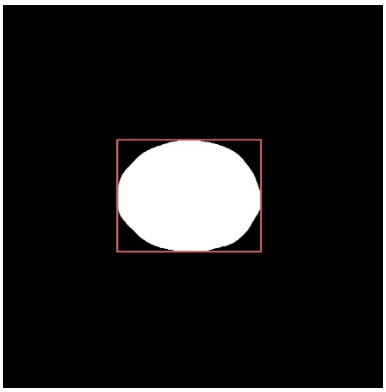

Figure 8- Determination of the image's width, height and ratio of white

Table 1- Pixel ratios obtained from the watermelon images based on the segmentation process

Height	***Widht***	***Ratio of white***	***Weight***
0.372403604	0.445519810	0.139808444	4.885
0.385702246	0.454783085	0.147930963	5.465
0.380525952	0.489560750	0.156355111	6.760
0.472652356	0.470154164	0.171111111	7.300
0.399590102	0.560533784	0.180710667	8.575
0.370586360	0.588517670	0.207366197	9.150
0.410002223	0.632022333	0.225555555	10.055
0.500002233	0.610022340	0.259990526	11.330
0.423666657	0.445569890	0.288002222	12.325
0.571152700	0.558889777	0.329933338	13.708
0.441111223	0.502222256	0.343333333	14.120
…	…	…	…

Figure 9 shows a comparison of the ratios of white, width, and height obtained from watermelon images. To compare the weight data with other data, it was increased the white, width, and height ratios by multiplying them by certain coefficients and evaluated the results by comparing the data on the graphs. When examining the graphs, it was found that the data with a graph

similar to the weight change is the data that was the white ratio. Upon comparing the data, it was apparent that the graphs were not significantly distant from each other, and the correct results will be obtained by using these data in weight prediction.

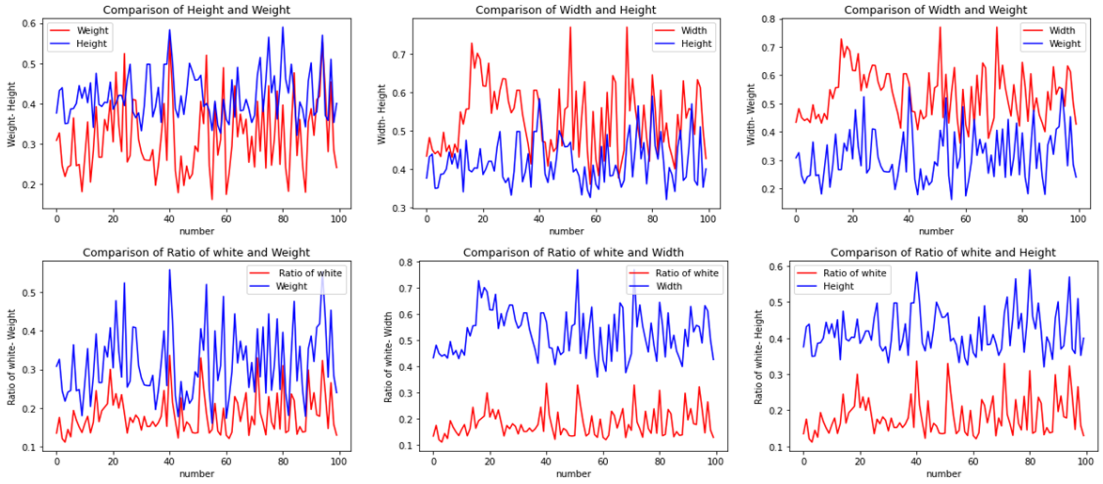

Figure 9- Comparison of the data obtained from the images of the watermelons

3.3. Weight prediction

Weight prediction was performed using regression methods, with the watermelon weights as output data and the ratios obtained from the images as input data. MSE, MAE, RMSE, and R^2 score values were calculated from the training results of each model and added in Table 3. Upon analysis of the regression results, it is evident that decision tree and random forest models show higher training success for weight prediction. The random forest regression model produced the best result, whereas the SGD model yielded the worst outcome, according to the training success. However, the R^2 scores- indicating the percentage success in regression training- were lower in watermelon as opposed to the higher scores obtained in apple, orange, and tomato data training. The findings show that watermelon achieved the lowest success in training, with 91.12%, whereas in training success of apple scored 99.44%, tomato scored 99.89%, and orange scored 99.96%. This low training success for watermelon can be attributed to its weight and the amount of space it occupies in the image, which varies more than other products.

Table 2- Results of regression

Fruit and vegetable	*Model*	*MSE*	*MAE*	*RMSE*	*R^2 score*
Watermelon	**MLP**	2.147	68.383	14.652	0.6794
	SVM	4.071	1.279	20.176	0.3922
	Linear	3.329	110.423	18.742	0.5029
	SGD	3.728	1.371	19.309	0.4433
	DT	0.612	0.234	0.7823	0.9086
	RF	0.637	0.221	0.7982	**0.9112**
Apple	**MLP**	59.162	6.012	7.6917	0.8923
	SVM	50.0782	5.6373	7.077	0.9088
	Linear	39.66	4.8932	6.2982	0.9278
	SGD	74.778	6.8857	8.6475	0.8639
	DT	4.5534	0.5128	2.1339	0.9917
	RF	3.0878	0.7917	1.7572	**0.9944**
Tomato	**MLP**	19.547	3.0916	4.4209	0.9853
	SVM	244.87	9.344	15.649	0.815
	Linear	35.192	4.4524	5.9596	0.9732
	SGD	222.39	10.3075	14.913	0.8319
	DT	1.6654	0.212	1.2905	0.9987
	RF	1.4368	0.3713	1.1987	**0.9989**
Orange	**MLP**	8.331	2.152	2.8864	0.983
	SVM	12.733	2.4505	3.5684	0.974
	Linear	7.759	2.0114	2.786	0.9842
	SGD	28.7058	4.029	5.356	0.9414
	DT	0.2013	0.0817	0.4487	**0.9996**
	RF	0.2025	0.1946	0.45	**0.9996**

The graphs shown in Figure 10 were drawn for each model to show the actual and predicted values together and to evaluate the results of the weight predictions made by the regression models. The graphs shown in Figure 10 were drawn for each model

to show the actual and predicted values together and to evaluate the results of the weight predictions made by the regression models. In these graphs, the values on the diagonal line indicate the success of the prediction. The graphs show the weight predictions made by MLP, SVM, Linear, SGD, RF, and DT models for watermelon, apple, orange, and tomato. Although the success rate of predictions in random forest and decision tree models, where values are concentrated on the diagonal line in the graphs, is high, the data is scattered in models such as SGD and SVM, so the success rate is low. Since watermelon has low weight predictions, in the graphs in the first column, the actual and predicted values are scattered around the diagonal line. Because the success rate is high for tomatoes and oranges, the actual and predicted values are concentrated on a diagonal line.

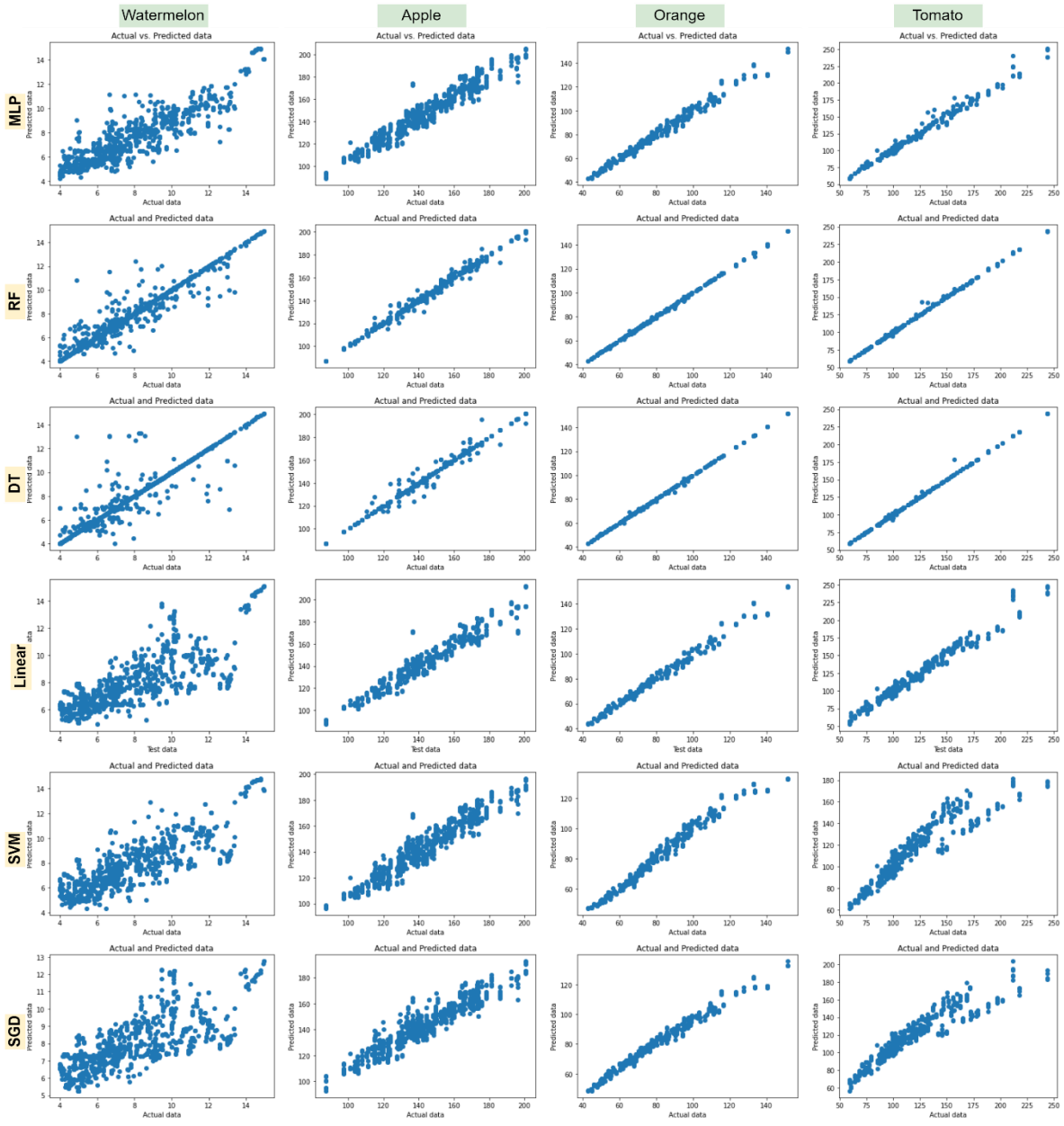

Figure 10- Prediction graphs based on regression results

The graphs shown in Figure 11 were created to compare some weights selected from the test data and the predictions made by the models used in the regression. Graphs were drawn using 1000 data selected from the test data. According to these results, it is seen that the differences in the predictions made in linear models from the actual weights are high, while the differences are low in non-linear models. Findings showed noteworthy disparities between actual weights and predicted weights with the linear models. However, non-linear models showed comparatively lower discrepancies. The graphs display real values in red and predicted values in blue. The graphs where the red color disappears under the blue color are RF and DT models with high prediction success. When analyzing the graphs where the red color increases, the worst predictions were made for watermelon. The linear, SVM, and SGD models were also the worst predictors.

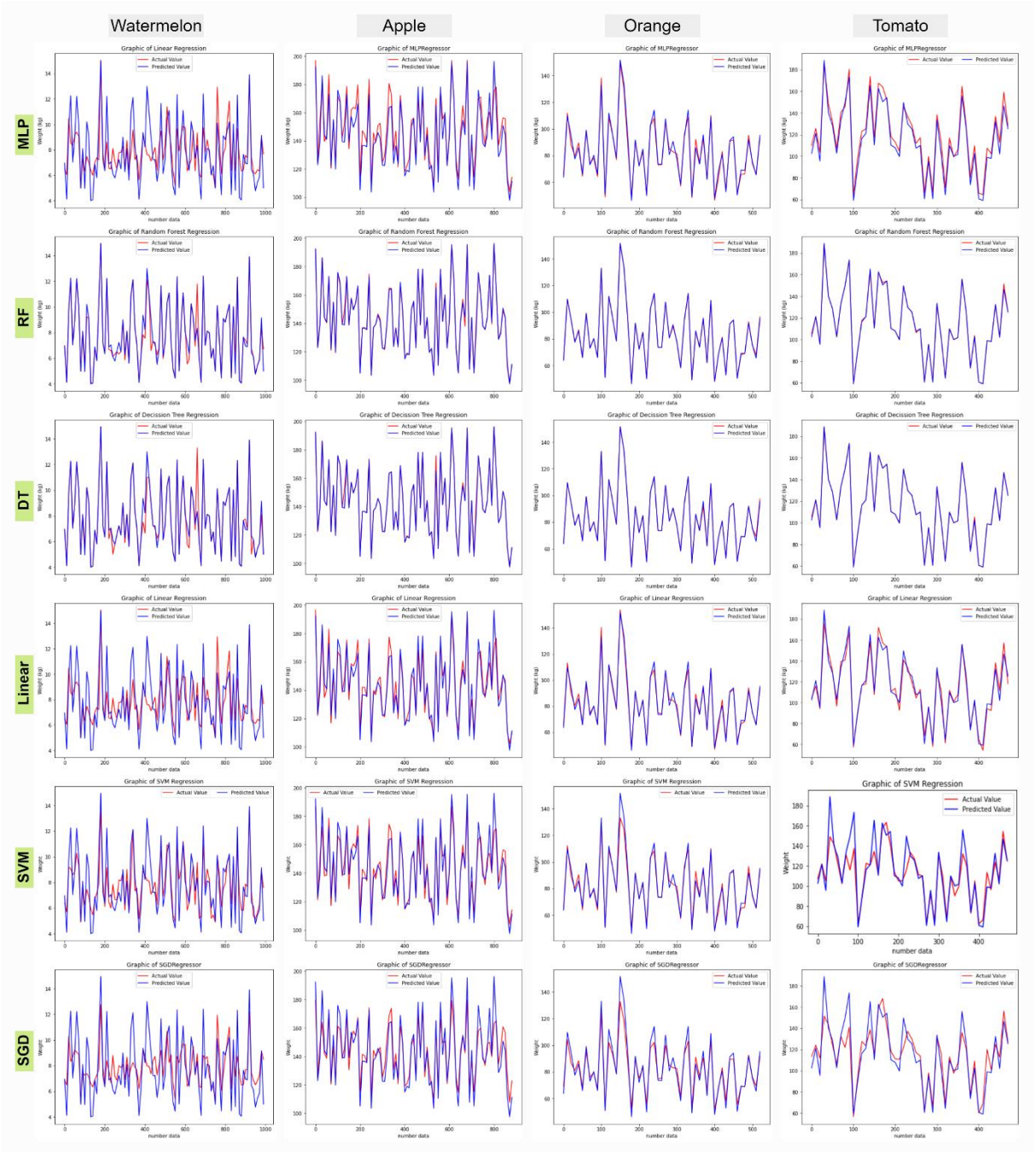

Figure 11- Comparing the predictions derived from the models with the actual results

4. Discussions

In this study, mask images of round-shaped vegetables and fruits were obtained by segmenting images taken at equal distances with a CNN based U-Net architecture. In the segmentation training, the highest success rate was obtained for orange, with 99.96%. When the literature on image segmentation is examined, it is seen that the success rate varies between 70% and 99.88%, with the degree of success depending on the complexity of the process. As the background complexity increases, the success rate of image segmentation decreases. The segmentation result was high due to the clean backgrounds of fruits and vegetables and the presence of a single product in each image. Rudenko et al. (2020) posited that segmentation success may decline when complex images or multiple products are present in the same image. In instances where there are multiple products in the image or the products are overlapping, the mask of the objects may not be fully displayed. In the segmentation and object detection studies of Bargoti & Underwood (2024) and Kang & Chen (2020), the objects in close proximity to the apple image were identified as apples in instances where the apples on the tree were obstructed by leaves and branches. This was achieved through the use of the WS and DasNet-v2 algorithms. By utilizing these algorithms, object detection can be performed in the presence of more than one product in the image. Furthermore, in images where multiple products are displayed together in a greengrocer's aisle or market stalls, the masks of the apples beneath the top apples appear to be missing. With object detection, the missing

masks are displayed as a whole, and weight estimation can be made using the data obtained from these masks. In addition to the images captured at equal distances as in this study, images are also captured with the assistance of a LiDAR sensor and distance sensors (Xu et al. 2024; Jeong et al. 2024). While distance is not a significant factor in images captured at equal distance, it becomes crucial in images obtained through sensor technology. With the advent of applications on mobile devices utilizing sensor technology, consumers will have more expedient access to information regarding the weight of a product by obtaining data from images of the product in various environments, negating the need for equal distance and creating more precise weight estimates. In environments where fruits such as apples, oranges and tomatoes are present, it has been observed that weight estimation can be improved by identifying the fruits and completing the missing ones in cases where the product is not fully visible in the image.

As with the generation of the mask area, width and height ratios, data are generated with features such as the length and width of the actual product, the number of products, the volume and area of the product by immersion in water, and agronomic and phonologic factors (Teoh & Syaifudin 2007; Rad et al. 2015; Naroui Rad et al. 2017). Furthermore, an alternative method for determining the area covered by the product using a point cloud or for obtaining product information by detecting the endpoints of the product has also been developed. The results of this study indicate that not only round-shaped vegetables and fruits, but also non-round products such as radish, soybean, cucumber, and eggplant, can be segmented and various data can be obtained from the images. This allows for the estimation of weight for these products. By using masks of products such as carrots, peppers, aborigines, and bananas, datasets such as area, width, and height ratios can be obtained. Moreover, in this study, data comprising ratios with low values were multiplied by specific numbers, and the consistency of the data was evaluated using graphs. In the estimation of vegetable and fruit weights, studies on small-sized products are typically conducted, whereas there are few studies on the weight of products such as watermelon. Given the variability in the weights of large-sized products, segmentation and weight estimates are often low.

Table 3- Studies on weight prediction

Studies	*Obtaining Data*	*Prediction Model*	*Score*	*Predicted Weight*
Kamiwaki & Fukuda (2024)	3D image processing	RF	0.95	Radish
Jeong et al. (2024)	Camera and LiDAR	HRNet	0.95	Strawberry
Duc et al. (2023)	Digital image analysis	RF	0.98	Soybean
Xu et al. (2024)	LiDAR	DNN	0.979	Sweetpotato
Nyalala et al. (2019)	Computer vision	RBF-SVM	0.9694	Cherry tomato
Huynh et al. (2020)	Camera	Equal slices	0.967	Cucumber
Ying-Kai et al. (2023)	Computer vision	ANN	0.986	Dragon fruit
Teoh & Syaifudin (2007)	Image processing	Statistical regression	0.9769	Chokanan mango
Xu et al. (2020)	UAV Remote sensing data	ANN	0.8170	Cotton boll
Naroui Rad et al. (2017)	Agronomic and phenologic factor	ANN	0.93	Eggplant
Rad et al. (2015)	Fruit sizes	ANN	0.88	Melon
Faisal et al. (2020)	Computer vision	SVM-Linear	0.84	Date fruit
Our's study	Image processing	RF	**0.9996**	Orange

Table 3 presents a selection of studies that estimate the weight of various round vegetables and fruits, including watermelon, apple, orange and tomato, as well as products with different shapes. This studies are achieved by obtaining data from image or real dimensions. The weight estimation model employed in this study allows for the estimation of fruit weight in studies investigating the weight of ripe fruit, as well as in studies following the development of the product. The studies yielded a success rate of between 84% (Xu et al. 2020) and 99% (Ying-Kai et al. 2023) in predicting fruit development and mature fruit weight. A comparison of the success rates of weight predictions obtained for each product in the study with those presented in the table reveals that satisfactory results have been achieved. It has been demonstrated that machine learning models are more successful at making predictions in studies with less data. In this study, machine learning models such as RF, MLP, DT, Linear, SGD and SVM were employed due to the lack of a large dataset and limited variety. The results indicated that the RF and DT models exhibited the highest prediction success rates for all products. Conversely, the SVM and linear models demonstrated the lowest prediction accuracy. The results of the RF model are particularly useful for predicting the weight of fruits and vegetables. While a small number of regression models were used in many studies, six models were used in this study, and the most appropriate prediction model was determined. Thus, the results of this study demonstrate that nonlinear RF and DT models achieve higher success rates than linear models in proportion to the diversity and complexity of the product in the image. The developed model has shown superior prediction performance by selecting the model with the highest success rate.

5. Conclusions

In this study, the model was developed to predict the weights of fruits and vegetables such as watermelons, apples, oranges and tomatoes using data obtained from their images taken at equal distances. To collect the images, products were purchased from markets and greengrocers, their images were taken and weighed, and their weights were recorded. The images were segmented utilizing the U-Net architecture, the area covered by the product was colored white, while the other pixels were colored black. Three new data were generated for each image such as the ratio of white pixels to all pixels, the ratio of the width of the rectangle to the width of the image when white pixels are contained in a rectangle, and the ratio of the height of the rectangle to the height

of the image. Weights were predicted using the data obtained from the image. In the regression models used in the model, good predictions were made with high success rates in random forest and decision tree models, while low predictions were made with low success rates in models such as linear and SGD. The best prediction success percentages were 91.12% for watermelon, 99.14% for apple, 99.96% for orange, and 99.89% for tomato. According to these results, nonlinear models were more successful in predicting weights than linear models. In addition, it has been observed that linear models in regression and classification models have lower scores than models such as non-linear ANN, DT and RF. With live body weight prediction, the body weight of the animal is known before the animal is disturbed and slaughtered. Similarly, non-destructive weight estimation of fruits and vegetables can be performed without damaging or cutting them. It is also possible to predict the weight of fruits and vegetables such as watermelons, apples, oranges, and tomatoes in cases where it is not possible to weigh it, providing convenience in the fields or in environments where there are no scales. At the same time, it is predicted that the estimated weight of the watermelons in the watermelon fields can be used in bargaining, such as selling products on the field. Similarly, at the time of harvest, tomatoes in the field and apples and oranges on the trees can be sold wholesale without weighing. Furthermore, given the recent surge in infectious diseases, the transmission of viruses through hand-to-hand contact during product selection and weighing will be minimized.

References

Akkol S, Akilli A & Cemal I (2017). Comparison of artificial neural network and multiple linear regression for prediction of live weight in hair goats. *Yyu J. Agric. Sci* 27: 21-29. DOI: 10.29133/yyutbd.263968

Alzubaidi L, Zhang J, Humaidi A J, Al-Dujaili A, Duan Y, Al-Shamma O, Santamaria J, Fadhel M A, Al-Amidie M & Farhan L (2021). Review of deep learning: Concepts, CNN architectures, challenges, applications, future directions. *Journal of big Data* 8(1): 1-74. DOI: 10.1186/s40537-021-00444-8

Babajide O, Hissam T, Anna P, Anatoliy G, Astrup A, Alfredo Martinez J, Oppert J M & Sørensen T I (2020). A machine learning approach to short-term body weight prediction in a dietary intervention program. *In Computational Science–ICCS 2020: 20th International Conference, Proceedings, Part IV 20* (pp. 441-455). DOI: 10.1007/978-3-030-50423-6_33

Bangdiwala S I (2018). Regression: simple linear. *International journal of injury control and safety promotion* 25(1): 113-115. DOI: 10.1080/17457300.2018.1426702

Barbole D K, Jadhav P M & Patil S B (2021). A review on fruit detection and segmentation techniques in agricultural field. *In International Conference on Image Processing and Capsule Networks* (pp. 269-288). Springer, Cham. DOI: 10.1007/978-3-030-84760-9_24

Bargoti S & Underwood J P (2017). Image segmentation for fruit detection and yield estimation in apple orchards. *Journal of Field Robotics* 34(6): 1039-1060. DOI:10.1002/rob.21699

Breiman L (2001). Random forests. *Machine learning*, 45: 5-32. DOI: 10.1023/A:1010933404324

Castro C A D O, Resende R T, Kuki K N, Carneiro V Q, Marcatti G E, Cruz C D & Motoike S Y (2017). High-performance prediction of macauba fruit biomass for agricultural and industrial purposes using Artificial Neural Networks. *Industrial Crops and Products*, 108: 806-813. DOI: 10.1016/j.indcrop.2017.07.031

Chicchón Apaza M Á, Monzón H M B & Alcarria R (2020). Semantic segmentation of weeds and crops in multispectral images by using a Convolutional Neural Networks based on u-net. *In International Conference on Applied Technologies* (pp. 473-485). Springer, Cham. DOI: 10.1007/978-3-030-42520-3_38

Cornelis C, Deschrijver G & Kerre E E (2006). Advances and challenges in interval-valued fuzzy logic. *Fuzzy sets and systems*, 157(5): 622-627. DOI: 10.1016/j.fss.2005.10.007

Duc N T, Ramlal A, Rajendran A, Raju D, Lal S K, Kumar S, Sahoo R N & Chinnusamy V (2023). Image-based phenotyping of seed architectural traits and prediction of seed weight using machine learning models in soybean. *Frontiers in Plant Science*, 14: 1206357. DOI: 10.3389/fpls.2023.1206357

Faisal M, Albogamy F, Elgibreen H, Algabri M & Alqershi F A (2020). Deep learning and computer vision for estimating date fruits type, maturity level, and weight. *IEEE Access*, 8: 206770-206782. DOI: 10.1109/ACCESS.2020.3037948

Fernandes A F, Turra E M, de Alvarenga É R, Passafaro T L, Lopes F B, Alves G F, Singh V & Rosa G J (2020). Deep Learning image segmentation for extraction of fish body measurements and prediction of body weight and carcass traits in Nile tilapia. *Computers and electronics in agriculture*, 170: 105274. DOI: 10.1016/j.compag.2020.105274

Friha O, Ferrag M A, Shu L, Maglaras L & Wang X (2021). Internet of Things for the Future of Smart Agriculture: A Comprehensive Survey of Emerging Technologies, *IEEE/CAA J. Autom. Sinica*, 8(4): 718-752. DOI: 10.1109/JAS.2021.1003925

Gondchawar N & Kawitkar R S (2016). IoT based smart agriculture. *International Journal of advanced research in Computer and Communication Engineering*, 5(6): 838-842. DOI: 10.1088/1757-899X/1212/1/012047

Guo Y, Liu Y, Georgiou T & Lew M S (2018). A review of semantic segmentation using deep neural networks. *International journal of multimedia information retrieval*, 7(2): 87-93. DOI: 10.1007/s13735-017-0141-z

Han H G & Qiao J F (2013). A structure optimisation algorithm for feedforward neural network construction. *Neurocomputing*, 99: 347-357. DOI: 10.1016/j.neucom.2012.07.023

Huynh T, Tran L & Dao S (2020). Real-time size and mass estimation of slender axi-symmetric fruit/vegetable using a single top view image. *Sensors*, 20(18): 5406. DOI: 10.3390/s20185406

Jeong H, Moon H, Jeong Y, Kwon H, Kim C, Lee Y, Yang S M & Kim S (2024). Automated Technology for Strawberry Size Measurement and Weight Prediction Using AI. *IEEE Access*. 12: 14157-14167. DOI: 10.1109/ACCESS.2024.3356118

Kang H & Chen C (2020). Fruit detection, segmentation and 3D visualisation of environments in apple orchards. *Computers and Electronics in Agriculture, 171*: 105302. DOI: 10.1016/j.compag.2020.105302

Kassim M R M (2020). Iot applications in smart agriculture: Issues and challenges. *In 2020 IEEE conference on open systems (ICOS)* (pp. 19-24). IEEE. DOI: 10.1109/ICOS50156.2020.9293672

Kamiwaki Y & Fukuda S (2024). A Machine Learning-Assisted Three-Dimensional Image Analysis for Weight Estimation of Radish. *Horticulturae*, 10(2): 142. DOI: 10.3390/horticulturae10020142

Lee C Y (2023). Fruit Weight Predicting by Using Hybrid Learning. *In International Conference on Technologies and Applications of Artificial Intelligence*, (pp. 81-91). Singapore. DOI: 26912554

Li J, Sarma K V, Ho K C, Gertych A, Knudsen B S & Arnold C W (2017). A multi-scale u-net for semantic segmentation of histological images from radical prostatectomies. *In AMIA Annual Symposium Proceedings*. (pp. 1140). American Medical Informatics Association. DOI: PMC5977596

Lin B W, Yoshida D, Quinn J & Strehlow M (2009). A better way to estimate adult patients' weights. *The American journal of emergency medicine*, 27(9): 1060-1064. DOI: 10.1016/j.ajem.2008.08.018

Mahesh B (2020). Machine learning algorithms-a review. *International Journal of Science and Research (IJSR)*, 9: 381-386. DOI: 10.21275/ART20203995

Naroui Rad M R, Ghalandarzehi A & Koohpaygani J A (2017). Predicting eggplant individual fruit weight using an artificial neural network. *International Journal of Vegetable Science*, 23(4): 331-339. DOI: 10.1080/19315260.2017.1290001

Nyalala I, Okinda C, Nyalala L, Makange N, Chao Q, Chao L, Yousaf K & Chen K (2019). Tomato volume and mass estimation using computer vision and machine learning algorithms: Cherry tomato model. *Journal of Food Engineering*, 263: 288-298. DOI: 10.1016/j.jfoodeng.2019.07.012

O'Grady M J, Langton D & O'Hare G M P (2019). Edge computing: A tractable model for smart agriculture. *Artificial Intelligence in Agriculture*, 3: 42-51. DOI: 10.1016/j.aiia.2019.12.001

Ozkaya S (2013). The prediction of live weight from body measurements on female Holstein calves by digital image analysis. *The Journal of Agricultural Science*, 151(4): 570-576. DOI: 10.1017/S002185961200086X

Park J, Kwak Y H, Jung J Y, Lee J H, Jang H Y, Kim H B & Hong K J (2012). A new age-based formula for estimating weight of Korean children. *Resuscitation*, 83(9): 1129-1134. DOI: https://doi.org/10.1016/j.resuscitation.2012.01.023

Pathan M, Patel N, Yagnik H & Shah M (2020). Artificial cognition for applications in smart agriculture: A comprehensive review. *Artificial Intelligence in Agriculture*, 4: 81-95. DOI: 10.1016/j.aiia.2020.06.001

Pekel E (2020). Estimation of soil moisture using decision tree regression. *Theoretical and Applied Climatology*, 139(3-4): 1111-1119. DOI: 10.1007/s00704-019-03048-8

Rad M R N, Fanaei H R & Rad M R P (2015). Application of Artificial Neural Networks to predict the final fruit weight and random forest to select important variables in native population of melon (Cucumis melo L.). *Scientia Horticulturae*, 181: 108-112. DOI: https://doi.org/10.1016/j.scienta.2014.10.025

Rozario L J, Rahman T & Uddin M S (2016). Segmentation of the region of defects in fruits and vegetables. *International Journal of Computer Science and Information Security*, 14(5): 399-406. https://www.researchgate.net/publication/304253402

Rudenko O, Megel Y, Bezsonov O & Rybalka A (2020). Cattle breed identification and live weight evaluation on the basis of machine learning and computer vision. *In CMIS* (pp.939-954). https://ceur-ws.org/Vol-2608/paper70.pdf

Teoh C C & Syaifudin A M (2007). Image processing and analysis techniques for estimating weight of Chokanan mangoes. *Journal of Tropical Agriculture and Food Science*, 35(1): 183. DOI: http://jtafs.mardi.gov.my/jtafs/35-1/Chokanan%20mangoes.pdf

Xiao J & Zhou Z (2020). Research progress of RNN language model. *In 2020 IEEE International Conference on Artificial Intelligence and Computer Applications (ICAICA)* (pp. 1285-1288). IEEE. DOI: 10.1109/ICAICA50127.2020.9182390

Xu J, Lu Y, Olaniyi E & Harvey L (2024). Online volume measurement of sweetpotatoes by A LiDAR-based machine vision system. *Journal of Food Engineering*, 361: 111725. DOI: 10.1016/j.jfoodeng.2023.111725

Xu W, Yang W, Chen S, Wu C, Chen P & Lan Y (2020). Establishing a model to predict the single boll weight of cotton in northern Xinjiang by using high resolution UAV remote sensing data. *Computers and Electronics in Agriculture*, 179: 105762. DOI: https://doi.org/10.1016/j.compag.2020.105762

Wu C H, Ho J M & Lee D T (2004). Travel-time prediction with support vector regression. *IEEE transactions on intelligent transportation systems*, 5(4): 276-281. DOI: 10.1109/TITS.2004.837813

Yan Q, Ding L, Wei H, Wang X, Jiang C & Degen A (2019). Body weight estimation of yaks using body measurements from image analysis. *Measurement*, 140: 76-80. DOI: 10.1016/j.measurement.2019.03.021

Ying-kai L, Feng-nan S, Qiao C, Ming-wei X, Chen-di L, Wen-tao L & Xue-cheng Z (2023). Dragon fruit weight estimation based on machine vision and machine learning. *Food and Machinery*, 39(7): 99-103. DOI: https://www.ifoodmm.cn/journal/vol39/iss7/15/

Yu Y, Si X, Hu C & Zhang J (2019). A review of recurrent neural networks: LSTM cells and network architectures. *Neural computation* 31(7): 1235-1270. DOI: 10.1162/neco_a_01199

Zhou X Y & Yang G Z (2019). Normalization in training U-Net for 2-D biomedical semantic segmentation. *IEEE Robotics and Automation Letters*, 4(2): 1792-1799. DOI: 10.1109/LRA.2019.2896518

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Variations in the Relative Abundance of Hemipteran Species in Different Seasons and Stages of Rice Growth Depending on Weather Variations

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ABSTRACT
Rompin has played an active role in Malaysia's rice production for several decades. However, rice production faces a threat, particularly from the hemipteran insect pests. There is limited documentation on the abundance of these insects and their relationship with weather factors. Therefore, this study aimed to determine the abundance of hemipterans in different growth stages and to understand the effects of weather factors on their population in rice fields. The study was conducted in farmers' rice fields in Rompin, Pahang, Malaysia, during the main and off-season rice planting. Sweep nets, yellow sticky traps, and yellow pan traps were utilized in each plot. Trapped insects were identified based on the rice planting seasons and growth stages. The trends of weather factors such as rainfall, temperature, light intensity, and wind speed were analysed and correlated with insect abundance. A total of 23 023 individuals belonging to six families and eleven species of the hemipteran order were recorded. Nine of these species were pests, namely *Leptocorisa oratorius* (Fabricius) (2.05%), *Maiestas dorsalis* (Motschulsky) (41.93%), *Nephotettix virescens* (Distant) (1.52%), *Nephotettix nigropictus* (Stål) (0.03%), *Scotinophara* sp. (4.92%), *Nilaparvata lugens* (Stål) (28.18%), *Sogatella furcifera* (Horváth) (17.75%), *Nezara viridula* (Linnaeus) (0.01%) and *Scotinophara coarctata* (Fabricius) (2.88%). The other two species were predators, *Cyrtorhinus lividipennis* (Reuter) (0.55%) and *Polytoxus fuscovittatus* (Stål) (0.19%). *Maiestas dorsalis*, *N. lugens*, *S. furcifera*, and *Scotinophara* sp. were found in significantly (df=10, F=5.707, P<0.01) higher numbers and exceptionally high during rice's late vegetative and early reproductive stages. The maximum temperature significantly (R^2>0.5 & P<0.05) increased during the main season, while wind speed increased significantly (R^2>0.5 & P<0.05) during the off-season. Wind speed significantly positive correlated (r>0.5 & P<0.05) with *N. virescens*, *S. furcifera*, *L. oratorius*, and *Scotinophara* sp. On the other hand, rainfall exhibited a significant negative correlation (r>-0.5 &P<0.05) with *L. oratorius*. Various pest species and their high populations in this study pose a significant threat to plants due to their preferences for different plant parts and strata.

Keywords: Hemiptera, Pest, Trap, Rice growth stage, Weather factors

1. Introduction

In 2021, Malaysia's total rice planted area was 647 859 hectares, which resulted in a total production of 2 428 893 tons (DOA 2022a). Specifically in Pahang state, the rice production amounted to 37 817 tons planted on 13 497 hectares of land (DOA 2022b). Pahang state ranked tenth among the 14 granary areas in Malaysia, with an average rice production of 2 802 kg/ha (DOA 2022). To ensure a sufficient supply of this essential food, the Rompin granary area has consistently played a significant role in rice production activities within Pahang state. In Rompin, rice was cultivated across a total area of 5 272 hectares, resulting in a production of 24 306 tons in 2021 with an average rice yield of 4 610 kg/ha (DOA 2022). However, similar to other rice planting areas, Rompin faces the threat of insect pests, particularly those from the hemipteran order. Hashim et al. (2017) discovered that in Penang, Hemipterans were the most prevalent throughout the night, with *Nilaparvata lugens* from the Delphacidae family being the most abundant. The study conducted by Razali et al. (2015) found that Tanjong Karang, Selangor likewise exhibited a high prevalence of hemipteran insects.

Hemiptera, also known as true bugs, is an insect order distinguished by their specialised mouthparts adapted for piercing and sucking. This group encompasses a wide range of insects, including planthoppers (Delphacidae), leafhoppers (Cicadellidae), broad-headed bugs (Alydidae), and seed bugs (Lygaeidae) (Schuh & Slater 1995; Duman & Mutlu 2019; Mutlu et al. 2016; Win et al. 2011; Abdullah et al. 2017). Hemipterans generally possess two sets of wings, with the forewings frequently exhibiting

partial hardening. They can be located in a wide range of habitats, spanning from land-based to water-based ecosystems. Hemipterans have important ecological roles as herbivores, predators, and occasional parasites. Certain organisms, such as aphids, are detrimental to agriculture, whilst others serve as advantageous predators that regulate pest populations. Due to their wide range of species and capacity to adjust to different environments, insects are an essential group in various ecosystems (Moir & Brennan 2007). Planthoppers are small insects that can harm rice crops by feeding on plant sap and spreading plant pathogens like viruses. Two species that are often found in rice fields are the brown planthopper, *Nilaparvata lugens* (Heong & Hardy 2009), and the white-backed planthopper, *Sogatella furcifera* (Zhou et al. 2008). When their population is high, *N. lugens* can cause "hopper burn" resulting in a 70% loss in yield (Krishnaiah et al. 2008). Rice leafhoppers, like the green leafhopper, *Nephotettix* spp., also feed on sap and can transmit Rice Tungro Baciliform Virus (RTBV) and Rice Tungro Spherical Virus (RTSV) (Dai & Beachy 2009). Rice stink bugs, such as *Leptocorisa* spp., feed on rice plants by piercing and sucking sap from the stems, leaves, and developing grains (Jauharlina et al. 2019). Rice seed bugs, on the other hand, feed on developing rice grains, potentially causing damage to the crop (Abdullah et al. 2017). While some hemipterans are considered pests in agriculture, others play important roles as pollinators or predators of other insects (Johnson & Triplehorn 2020).

Apart from pest insects, there are also predator insects from the hemipteran order, specifically the mirid bugs (Miridae). An example of a beneficial insect is *Cyrtorhinus lividipennis*, which feeds on rice pests like planthoppers and leafhoppers (Xiao et al. 2014). In addition to these terrestrial insects, there are a few aquatic species predators that can be found in rice fields, such as water striders (Gerridae), water scorpions (Nepidae), and backswimmers (Notonectidae). These insects are commonly found on the water surface of rice fields and they prey on smaller insects and aquatic organisms, thus helping to control pest populations. However, water boatmen (Corixidae) are herbivorous insects and feed on algae and aquatic plants (Shepard et al. 1987).

However, currently there is limited information available regarding the abundance of hemipterans and how weather factors influence their populations in Rompin's rice fields. Thus, the main goal of this study were to i) collect data on the population and distribution of hemipterans during different growth stages of rice plants, and ii) examine the relationship of weather factors on the population of hemipterans in the rice fields of Rompin, Pahang, Malaysia.

2. Material and Methods

2.1. Location and duration of study

The study was conducted in Kampung Paya Laka, Rompin, Pahang, Malaysia, which is a rice granary area (GPS coordinates: 103.384378 N, 2.799604 E), as shown in Figure 1. In Malaysia there are two rice planting seasons practiced by the farmers which were the main season and the off-season.

The main season is the optimal period for rice cultivation based on local climate conditions (rainy season) and does not rely heavily on irrigation systems. The main season is defined as the period during which rice is planted, with planting dates falling between August 1st and February 28th/29th of the following year. The off-season however, corresponds to the dry period when rice cultivation typically depends on irrigation systems (dry season). The off-season is defined as the period during which rice is planted, with planting dates falling between March 1st and July 31st of the current year (DOA 2022b). This study covered both main season (August 2017 to February 2018) and off-season (March to July 2018). The MR269 variety was cultivated by the farmers in Rompin, Pahang in both seasons. This variety is well-suited for cultivation throughout various granary regions in Malaysia. The crop reaches maturity between 104 and 109 days after planting, and the height of the plant ranges from 72 to 83 cm. It has the potential to yield 9.2 tonnes per hectare (DOA 2022b).

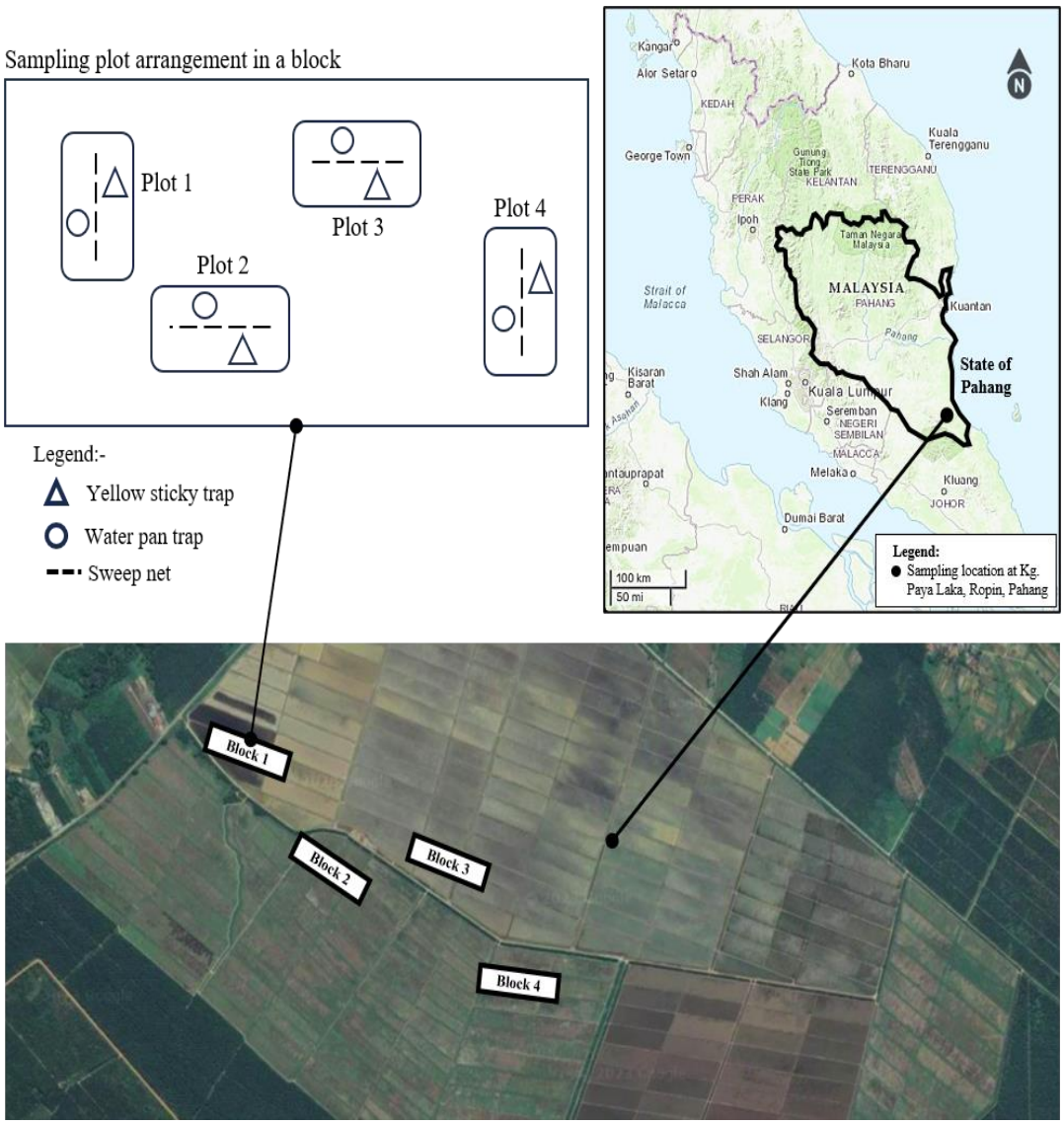

Figure 1- Location of study and sampling plot layout in Kampung Paya Laka, Rompin, Pahang, Malaysia

2.2. Insect sampling

Insect sampling in the main season was done starting from the 20th August 2017 until 29th October 2017 while the sampling during the off-season were commenced from 17th March 2018 until 26th May 2018. The sampling was conducted in the farmers' existing rice fields, with a block size of 1.2 hectares. The sampling consisted of four rice blocks, each containing four sampling plots. Each sampling plot had one yellow sticky trap and one yellow tray trap installed in each sampling plot. Sweep nets were also applied to each sampling plot based on the transect line. This resulted in four replications for each rice block.

Yellow stick traps were made from two-sided sticky plastic sheets (20 cm × 25 cm), which were mounted on a pole stand at the height of the rice plant canopy. The height of the yellow sticky traps was adjusted every sampling week based on the height of the rice plant. Yellow tray traps, on the other hand, were made of a 30 cm diameter by 10 cm deep plastic tray. They were filled with approximately 250 mL of detergent solution to allow arriving samples to sink. Yellow tray traps were set in open areas so that insects could clearly notice them. In terms of the yellow hue, both sticky and tray traps were referred to the *Reichs-Ausschuss für Lieferbedingungen* (RAL) CLASSIC colour collection system. The closest match between the RAL codes for yellow sticky and yellow tray trap was found to be 1026 (limunous yellow). Sticky and tray traps were replaced weekly, and the old ones were brought to the laboratory for counting. Observations using the tray trap were made once a week. The sweep net measures 38 cm in diameter, 50 cm in depth, and has a handle length of 1 metre. The sweep nets were swung in each plot to collect actively flying insects using a zig-zag pattern along a 10-meter transect (Figure 1) with 10 swings (one swing per meter). The action of sweeping was performed at the level of the plant canopy (Masika et al. 2017). Preventive measures were taken to avoid disturbing the rice flower and fruits while collecting samples. Data were collected for 11 consecutive weeks, starting two weeks after transplanting, with a seven-day interval between each collection. The field collection time began as early as 07.00 hours, due to the insects' active behaviour during that time (Kritsky & Young 2011).

2.3. Species identification and identification of role

Insect counting was conducted for each trap and insects were identified up to the species level using their external morphological characteristics (Elzinga 2004; Gullan & Cranston 2014; Johnson & Triplehorn 2020). The role of species in rice fields was determined whether they were categorised as pests, predators, or parasites. These characteristics were based on earlier research on the species' behaviour towards rice plants and other insects (Wilson & Claridge 1991; Heinrichs 2004; Pathak & Khan 1994; Reissig 1985; Shepard et al. 1987; Shepard et al. 1995).

2.4. Weather data

The weather data used in this study included rainfall (mm), temperature (°C), sunshine (hours), and wind speed (km/h). These data were obtained from the Meteorological Department of Malaysia (MET Malaysia). The daily data was averaged for each sampling date, the weather data were then plotted by sampling week basis according to each planting seasons using clustered column-line charts.

2.5. Data analysis

The number of individual insects during different planting seasons was determined using an independent Student's t-test. Meanwhile, the differences in rice growth stages between species were determined using ANOVA. Additionally, ANOVA was used to analyse the differences in the number of species during each planting season. Subsequently, any significant results were subjected to Tukey's Honestly Significant Difference (HSD) for multiple pairwise comparisons (Clewer & Scarisbrick 2001). The trend of each weather factor was determined using the coefficients a, b, R^2, and P from the regression analysis. An R^2 value greater than 0.5 was considered to indicate a significant increasing or decreasing trend at $P<0.05$. On the other hand, significant relationships between hemipteran species and weather factors were evaluated using Pearson's correlation. A Pearson's coefficient value, r greater than 0.6 at $P<0.05$, was considered to indicate a significant relationship (Southwood 2013). Results were analysed for overall data of insects from each plot in each planting season. However, the results presented in this study did not differentiate the number of insects collected between traps. All analyses were performed using IBM-SPSS version 22.

3. Results

A total of 11 species from six families of the hemipteran order were recorded during this study, conducted over two seasons of rice planting. Among these species, nine were pests and two were predators. The nine pest species identified were *Leptocorisa oratorius*, *Maiestas dorsalis*, *Nephotettix virescens*, *N. nigropictus*, *Scotinophara* sp., *Nilaparvata lugens*, *Sogatella furcifera*, *Nezara viridula*, and *Scotinophara coarctata*. The two predator species were *Cyrtorhinus lividipennis* and *Polytoxus fuscovittatus*. The four species with significantly higher numbers were *M. dorsalis*, *N. lugens*, *S. furcifera*, and *Scotinophara* sp., as shown in Table 1. This study also found significant differences in the number of individuals (df=10, F=5.707, P<0.01) among the hemipteran species. In Rompin, the species with significantly higher numbers were *M. dorsalis*, with 9654 individuals, followed by *N. lugens*, *S. furcifera*, and *Scotinophara* sp., with 6488, 4087, and 1132 individuals, respectively.

In terms of species abundance between planting seasons, the study showed a significant result for *L. oratorius* (df=10, t=-2.536 & P=0.020). It was found to be significantly higher during the off-season planting, with 396 individuals collected compared to 75 in the main season (Table 2). The rest of the hemipteran species were found to be insignificant between the main and off-seasons.

The weekly abundance of insects during the main season demonstrated significant differences (df=10; F=17.325 & P=0.0016) in the number of individuals among the collected species. Specifically, *N. lugens* (4605 individuals), *M. dorsalis* (6226 individuals), and *S. furcifera* (2609 individuals) were significantly more abundant in the third to fifth week of sampling. In contrast, during the off-season, there was a notable difference (df=10; F=8.112 & P=0.0048) in the number of insect individuals among Hemiptera species. Once again, *N. lugens* (1883 individuals), *M. dorsalis* (3428 individuals), and *S. furcifera* (1478 individuals) were significantly higher in the third to sixth week of sampling. Both planting seasons exhibited a surge in population during the late vegetative and early reproductive growth stages. Following this, the population of Hemipterans declined and remained relatively steady during the mature growth stage of rice (Figure 2).

Table 1 - The total number of hemipteran species collected according to different role of insect in both seasons of rice planting at Rompin, Pahang

No.	*Type*	*Family*	*Species*	*Common name*	*Total**
1	Pest	Alydidae	*Leptocorisa oratorius*	Slender rice bug	471 a
2		Cicadellidae	*Maiestas dorsalis*	Zig-zag winged rice leafhopper	9654 **c**
3			*Nephotettix virescens*	Green paddy leafhopper	349 a
4			*Nephotettix nigropictus*	Rice green leafhopper	7 a
5		Delphacidae	*Nilaparvata lugens*	Brown planthopper	6488**bc**
6			*Sogatella furcifera*	White-backed planthopper	4087**ab**
7		Pentatomidae	*Scotinophara* sp.	Rice bug	1132**ab**
8			*Nezara viridula*	Southern green stink bug	2 a
9			*Scotinophara coarctata*	Black rice bug	662 a
10	Predator	Miridae	*Cyrtorhinus lividipennis*	Plant bug	127 a
11		Reduviidae	*Polytoxus fuscovittatus*	Assassin bugs	44 a
				Total	23023

*: Same letter within this column was not significantly different at 0.05 confidence level

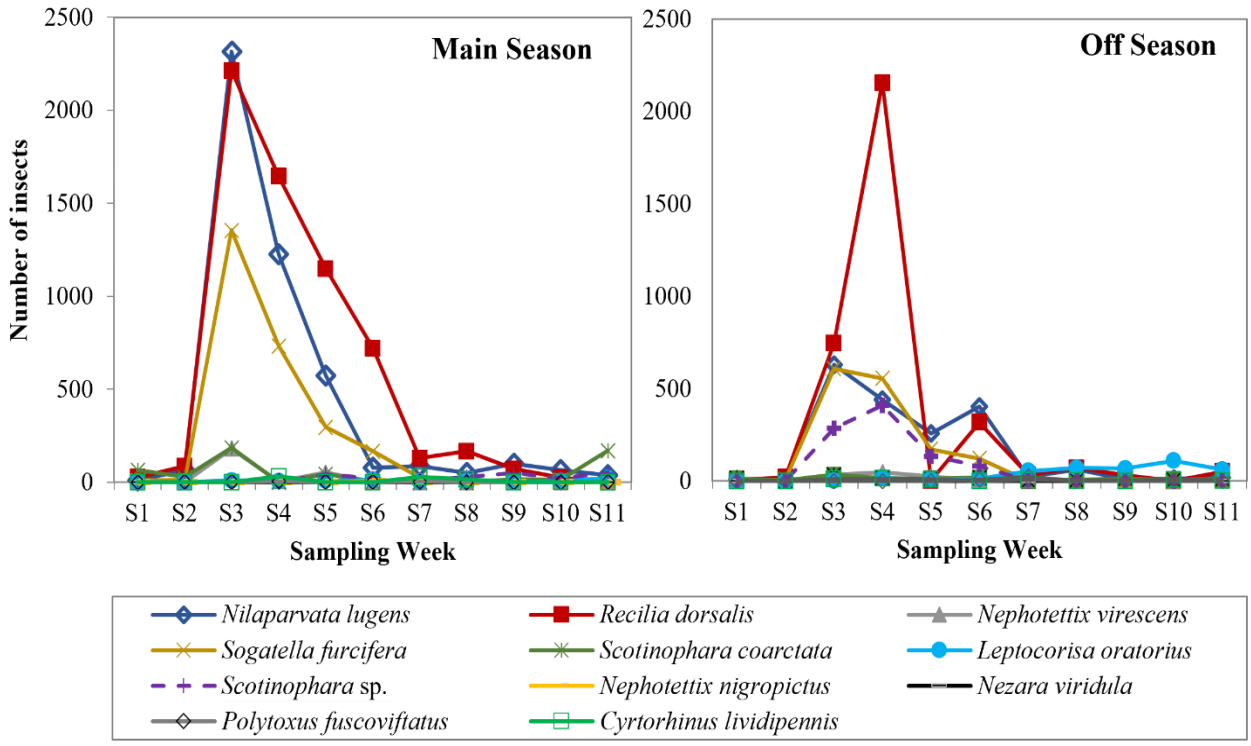

Figure 2 - Population of hemipterans species collected according to different rice growth stages during eleven sampling weeks in the main season (20th August 2017 - 29th October 2017) and off-season (17th March 2018 - 26th May 2018) of rice planting in Rompin, Pahang

The population of *Scotinophara* sp. was significantly lower in the vegetative stage, but significantly higher in the mature stage during the main season (df=2; F=5.175 & P=0.036) (Table 3). On the other hand, the population of *P. fuscovittatus* was significantly higher in the reproductive stage but significantly lower in the mature stage during the same season (df=2; F=6.994 & P=0.018) (Table 3). In the off-season, however, *L. oratorius* was significantly lower in the vegetative and reproductive stages but significantly higher in the mature stage (df=2; F=16.015 & P=0.002) (Table 3). Other insect species in this study were found not significant between main and off-seasons.

Table 2 - Total number of hemipterans species collected in main and off seasons of rice planting at Rompin, Pahang

Category	*Family*	*Species*	*Main Season*	*Off-Season*	*t (Sig.) value*
Pest	Alydidae	*Leptocorisa oratorius*	75	396	-2.536 (0.020)*
	Cicadellidae	*Maiestas dorsalis*	6226	3428	0.835 (0.414)
		Nephotettix virescens	238	111	0.666 (0.513)
		Nephotettix nigropictus	7	0	1.000 (0.329)
	Delphacidae	*Nilaparvata lugens*	4605	1883	1.078 (0.294)
		Sogatella furcifera	2609	1478	0.697 (0.494)
	Pentatomidae	*Scotinophara* sp.	218	914	-1.481 (0.154)
		Nezara viridula	2	0	1.000 (0.329)
		Scotinophara coarctata	526	136	1.738 (0.098)
Predator	Miridae	*Cyrtorhinus lividipennis*	76	51	0.578 (0.570)
	Reduviidae	*Polytoxus fuscovittatus*	13	31	-0.761 (0.456)

Note. * = P<0.05

The Figure 3 illustrates the weekly pattern and distribution of rainfall in the study area of Rompin. It was observed that the fifth sampling week (S6) experienced the highest average rainfall, measuring 148.6 mm, during the main planting season. Conversely, the lowest average rainfall of only 1.2 mm was recorded in the tenth sampling week (S10). Moreover, the third sampling week (S3) had the lowest minimum temperature, measuring 22.44 °C, whereas the highest maximum temperature, reaching 34.24 °C, was observed in the eighth sampling week (S8). Additionally, the tenth sampling week (S10) had the highest recorded average maximum sunlight hours of 7.74 hours, whereas the seventh sampling week (S7) had the lowest average minimum sunlight hours of 3.45 hours. Furthermore, the highest wind speed recorded was 3.05 km/h in the tenth sampling week (S10), while the lowest wind speed of 0.93 km/h was observed in the seventh sampling week (S7).

Table 3 - Mean number (± S.E) of hemipterans species collected in different growth stages of rice during the main and off-season

Species	*Main Season*			*Off-Season*		
	*V**	*R**	*M**	*V*	*R*	*M*
Leptocorisa oratorius	4.3 ± 2.8 a	6.7 ± 2.5 a	8.7 ± 4.2 a	0.3 ± 0.3 a	21.7 ± 10.8 a	77.0 ± 10.8 b
Recilia dorsalis	774.6 ± 718.8 a	910.2 ± 321.7 a	65.2 ± 36.5 a	256.6 ± 244.7 a	626.7 ± 514.3 a	37.7 ± 14.8 a
Nephotettix virescens	60.0 ± 60.0 a	14.5 ± 12.8 a	0.0 ± 0.0 a	11.6 ± 11.6 a	18.0 ± 11.4 a	1.0 ± 1.0 a
Scotinophara sp.	0.3 ± 0.3 a	17.2 ± 9.6 ab	37.0 ± 7.6 b	95.0 ± 95.0 a	156.2 ± 88.3 a	1.0 ± 1.0 a
Nilaparvata lugens	796.6 ± 759.3 a	491.2 ± 270.6 a	62.5 ± 12.9 a	218.3 ± 205.8 a	280.7 ± 94.4 a	26.2 ± 12.0 a
Sogatella furcifera	458.6 ± 447.6 a	305.0 ± 153.0 a	3.2 ± 3.2 a	207.3 ± 200.3 a	212.5 ± 120.0 a	1.5 ± 1.5 a
Scotinophara coarctata	92.3 ± 47.0 a	12.0 ± 10.3 a	50.2 ± 40.0 a	16.6 ± 9.1 a	13.0 ± 3.4 a	8.5 ± 2.0 a
Cyrtorhinus lividipennis	0.0 ± 0.0 a	14.7 ± 8.5 a	4.2 ± 3.9 a	3.3 ± 3.3 a	6.7 ± 2.6 a	3.5 ± 1.9 a
Polytoxus fuscoviftatus	0.6 ± 0.3 ab	2.5 ± 0.6 b	0.2 ± 0.2 a	0.0 ± 0.0 a	7.5 ± 5.4 a	0.2 ± 0.2 a
Nephotettix nigropictus	0.0 ± 0.0 a	1.7 ± 1.7 a	0.0 ± 0.0 a	0.0 ± 0.0 a	0.0 ± 0.0 a	0.0 ± 0.0 a
Nezara viridula	0.0 ± 0.0 a	0.0 ± 0.0 a	0.5 ± 0.5 a	0.0 ± 0.0 a	0.0 ± 0.0 a	0.0 ± 0.0 a

Note. Row with the same letter was not significantly different at 0.05 confidence level.

In contrast, the weather conditions during the off-season for rice cultivation in Rompin showed that the highest average rainfall was recorded in the seventh sampling week (S7) with 98.6 mm, while the lowest average rainfall was in the second sampling week (S2) with only 2.1 mm. The lowest minimum temperature was 21.51 °C, recorded in the third sampling week (S3), while the highest maximum temperature was reached in the third week (S3) at 33.73 °C. The highest recorded average

sunshine hours was 7.6 hours in the tenth sampling week (S10), while the lowest average minimum sunshine hours were 2.75 hours in the seventh sampling week (S7). On the other hand, wind speed recorded its highest value of 2.72 km/h in the fourth sampling week (S4), while the lowest wind speed was 1.17 km/h in the seventh sampling week (S7).

During the main planting season, the study identified a significant positive trend in maximum temperature throughout the sampling weeks (Table 4), with an R^2 value of 0.534 and a significance level of $P<0.05$. In contrast, during the off-season, wind speed showed a significant trend with an R^2 value of 0.628 and a significance level of $P<0.01$. The study revealed a significant trend in wind speed, with an R^2 value of 0.628 and a significance level of $P<0.01$. However, no other weather factors showed significant trends within the sampling weeks.

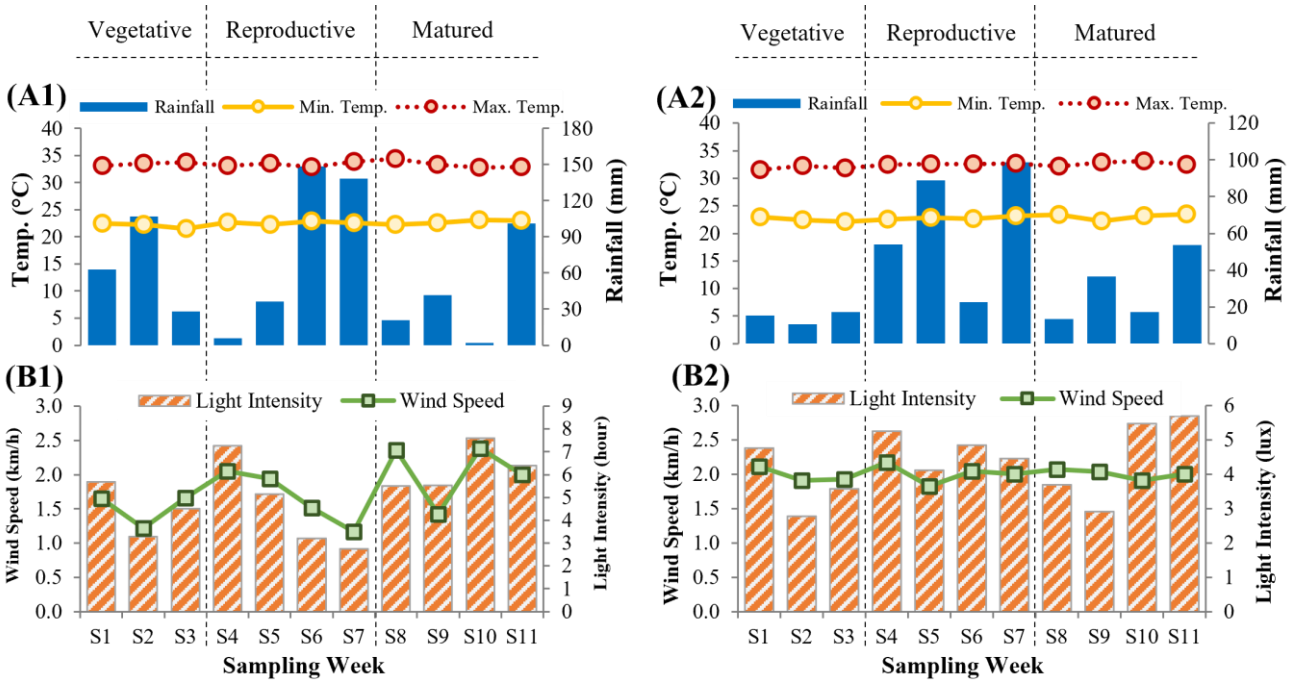

Figure 3 - Weather pattern in Rompin, Pahang, according to different rice growth stages. (A1) Rainfall, minimum and maximum temperature in the main planting season. (A2) Rainfall, minimum and maximum temperature in the off-season of planting. (B1) Light intensity and wind speed in the main planting season. (B2) Light intensity and wind speed in the off-season of planting

There was no statistically significant correlation between the hemipteran species and weather factors during the main planting season in Rompin (Table 5). Notably, a significant negative correlation (r=-0.655 & P=0.029) was observed between rainfall and *L. oratorius*. Additionally, wind speed exhibited substantial positive correlations with several species, including *N. virescens* (r=0.610 & P=0.046), *S. furcifera* (r=0.696 & P=0.017), *L. oratorius* (r=-0.709 & P=0.015), and *Scotinophara* sp. (r=0.614 & P=0.045) (Table 6).

4. Discussions

The insect species composition in Rompin fluctuates at any given time and depends on several factors, such as rice varieties, field management practices, the use of chemical pesticides, water quality, and weather conditions (Luo et al. 2014; Norazliza et al. 2014). This study found significantly higher populations of the following species: *Maiestas dorsalis*, *Nilaparvata lugens*, *Sogatella furcifera*, and *Scotinophara* sp. Similar species ranges have also been observed in other locations, as reported by various researchers (Abdul Hakim et al. 2013; Hegazy et al. 2021; Jauharlina et al. 2019; Jayanthi & Bambaradeniya 2006; Mariana et al. 2009; Norela et al. 2013; Yaakop et al. 2022). This probably due to favourable weather condition. Warm temperatures and high humidity during certain seasons which created an ideal condition for these pests to thrive. These conditions may also can accelerate their reproductive cycles and increase survival rates (Ahmed et al. 2013). On the other aspect, continuous monoculture of rice provides a stable and abundant food source for these pests, facilitating their population growth (Mir et al. 2022). The use of broad-spectrum insecticides can reduce populations of natural predators and parasitoids that help control these pests. Overreliance on chemical pesticides can lead to the development of resistance among pest populations, reducing the effectiveness of control measures (Gurr 2009).

Table 4 - Regression coefficient for weather factors trend analysis in Rompin, Pahang

Planting Season	*Weather Factors*	*Regression coefficient*		
		R^2	*Slope (x)*	*P value*
Main Season	Rainfall (mm)	0.039	1.862	0.560
	Min. temperature (°C)	0.250	0.070	0.118
	Max. temperature (°C)	0.534	0.101	0.011*****
	Light intensity (Lux)	0.103	0.096	0.335
	Wind speed (km/h)	0.002	-0.002	0.884
Off-Season	Rainfall (mm)	0.143	-3.531	0.252
	Min. temperature (°C)	0.138	0.046	0.261
	Max. temperature (°C)	0.012	-0.020	0.751
	Light intensity (Lux)	0.043	-0.064	0.539
	Wind speed (km/h)	0.628	-0.102	0.004******

Note. *= P<0.05, **= P<0.01

These pest insects are highly dangerous because they can spread viruses. Wei et al. (2018) identified four species of leafhoppers (*Nephotettix cincticeps*, *N. nigropictus*, *N. virescens*, and *M. dorsalis*) and three species of planthoppers (*Laodelphax striatellus*, *N. lugens*, and *S. furcifera*) as vectors of major viral diseases in rice plants. Therefore, it is crucial to pay more attention to the presence of these species and take early steps to control their populations during the initial stages of planting. The high incidence of these pests in rice fields poses a threat to the production of high-quality rice.

The study found that the population of pest species peaked during the late vegetative and early reproductive growth stages for both planting seasons. This was especially true for species such as *M. dorsalis*, *N. lugens*, *S. furcifera*, and *Scotinophara* sp.. After reaching its peak, the population of hemipterans declined and remained constant during the mature stage. Chancellor et al. (1996) also discovered similar findings, noting that *M. dorsalis* was more abundant during early rice planting in the Philippines. Additionally, Yang et al. (2017) demonstrated that *M. dorsalis* could transmit RSMV virus disease to the seedlings during the early planting stage. Wada and Nik Mohd. Noor (1992) observed that *N. lugens* and *S. furcifera* populations peaked in an early-planted field, while low levels were observed in a late-planted field. Furthermore, the population of *N. lugens* and *S. furcifera* tends to increase during the tillering and heading stages of rice plants, which are favorable for their reproduction and development (Faruq et al. 2018).

Table 5 - Correlation matrix between weather factors and insect species during the main season of rice planting in Rompin, Pahang

Species	*Coefficients (N=11)*	*Rainfall*	*Min. Temp.*	*Max. Temp.*	*Light Intensity*	*Wind Speed*
Nilaparvata lugens	Pearson's r	-0.015	-0.576	-0.341	-0.111	-0.096
	p-value	0.964	0.064	0.305	0.745	0.779
Maiestas dorsalis	Pearson's r	0.092	-0.563	-0.257	-0.036	-0.072
	p-value	0.788	0.071	0.446	0.917	0.833
Nephotettix virescens	Pearson's r	-0.069	-0.494	-0.413	-0.259	-0.401
	p-value	0.84	0.122	0.207	0.442	0.221
Sogatella furcifera	Pearson's r	-0.042	-0.579	-0.354	-0.077	-0.056
	p-value	0.903	0.062	0.285	0.822	0.87
Scotinophara coarctata	Pearson's r	-0.092	-0.072	-0.456	0.098	-0.255
	p-value	0.787	0.833	0.159	0.775	0.449
Leptocorisa oratorius	Pearson's r	0.029	0.282	0.079	0.536	-0.13
	p-value	0.934	0.401	0.817	0.089	0.704
Scotinophara sp.	Pearson's r	0.279	0.255	0.51	0.026	-0.233
	p-value	0.405	0.45	0.109	0.939	0.491
Nephotettix nigropictus	Pearson's r	-0.174	-0.092	0.142	0.175	0.135
	p-value	0.609	0.789	0.677	0.607	0.693
Nezara viridula	Pearson's r	-0.272	0.405	-0.156	-0.21	0.231
	p-value	0.419	0.217	0.648	0.536	0.494
Polytoxus fuscovittatus	Pearson's r	0.535	-0.1	0.157	0.304	0.31
	p-value	0.09	0.771	0.645	0.363	0.354
Cyrtorhinus lividipennis	Pearson's r	0.451	0.206	0.132	0.194	0.515
	p-value	0.164	0.544	0.699	0.567	0.105

Note. * P<0.05, ** P<0.01

Furthermore, *C. lividipennis* was found to coexist with *N. lugens*, which has been observed by other researchers in their studies as well (Wang et al. 2011; Yaakop et al. 2022). However, the population of *C. lividipennis* in this study was not significant enough to effectively regulate *N. lugens* incidence. *C. lividipennis* preys on the eggs and nymphs of *N. lugens*, using its piercing mouthparts to suck the eggs (Chua & Mikil 1989). To enhance the effectiveness of *C. lividipennis*, it is important to reduce the use of insecticides since most insecticides tested in the study by Reissig et al. (1982) significantly decreased the population of *C. lividipennis*. In other research on insecticides, endosulfan, chlorpyriphos, acephate, and methyl parathion have been considered safe for *C. lividipennis* based on specific spraying criteria (Preetha et al. 2010).

Table 6 - Correlation matrix between weather factors and insect species during the off-season of rice planting in Rompin, Pahang

Species	***Coefficients (N=11)***	***Rainfall***	***Min. Temp.***	***Max. Temp.***	***Light Intensity***	***Wind Speed***
Nilaparvata lugens	Pearson's r	0.295	-0.147	-0.151	0.149	0.598
	p-value	0.378	0.665	0.658	0.663	0.052
Maiestas dorsalis	Pearson's r	-0.125	-0.1	0.079	0.142	0.467
	p-value	0.714	0.769	0.817	0.677	0.148
Nephotettix virescens	Pearson's r	0.079	-0.393	-0.061	0.255	0.610
	p-value	0.819	0.232	0.859	0.449	0.046 *
Sogatella furcifera	Pearson's r	0.06	-0.219	-0.071	0.283	0.696
	p-value	0.862	0.517	0.835	0.399	0.017 *
Scotinophara coarctata	Pearson's r	0.224	-0.115	-0.06	0.173	0.572
	p-value	0.508	0.735	0.862	0.61	0.066
Leptocorisa oratorius	Pearson's r	-0.655	0.293	0.133	-0.046	-0.709
	p-value	0.029 *	0.382	0.698	0.892	0.015 *
Scotinophara sp.	Pearson's r	0.085	-0.277	-0.019	0.222	0.614
	p-value	0.804	0.409	0.956	0.512	0.045 *
Polytoxus fuscovittatus	Pearson's r	0.032	0.244	-0.515	-0.059	-0.124
	p-value	0.927	0.47	0.105	0.863	0.717
Cyrtorhinus lividipennis	Pearson's r	-0.278	-0.466	-0.137	0.459	0.431
	p-value	0.407	0.149	0.689	0.156	0.186

Note. *= P<0.05, **= P<0.01

The trend of weather factors in this study seems to be consistent in both planting seasons, except for the maximum temperature in the main season and the wind speed in the off-season. A survey conducted in granary areas in Malaysia on climate change revealed a noticeable increase in both maximum and minimum temperatures. It is also predicted that the average maximum and minimum temperatures in these Malaysian granary areas will continue to rise until 2045. However, the trend in rainfall showed a somewhat insignificant positive trend (Tan et al. 2021).

The influence of climate on insect incidence depends on the preferences of each species on rice plant parts. If they are in exposed positions, such as at the top (rice grains), they will be more easily affected. These species require alternative shelters to hide from unfavourable weather conditions such as strong wind, heavy rain, and high temperatures. If they are in a sheltered location, such as at the base of the plant or just above the water creases, insects are less affected by the weather. *L. oratorius* was found to have a significant negative correlation with rainfall and wind speed, meaning that higher rainfall and wind speed can reduce their population. *L. oratorius* usually attacks rice grains during the milky stage, when the rice grains are located at the topmost part of the rice plant (Van den Berg & Soehardi 2000). In this position, insects, particularly *L. oratorius*, are more exposed to the weather than the lower parts of the rice plant. Therefore, they are more susceptible to weather conditions, especially rainfall and wind speed. Since *L. oratorius* is commonly found in the upper part of rice plants, they are easily regulated by rainfall and wind. The incidence of *L. oratorius* in Assam also revealed a similar relationship with rainfall, and a significant positive correlation was also shown with sunshine hours (Das et al. 2021). In other studies, the minimum temperature has a significant negative correlation with *L. oratorius*, while no significance was found with the maximum temperature (Raj Kumar et al. 2018). However, Khare et al. (2020) found a positive correlation between relative humidity and *L. oratorius*, whereas the other parameters negatively correlated with the *L. oratorius* population. Since the weather factor has less influence on the insect population, the adaptation of agricultural practices at the farm level is critical to prevent more significant attacks by pest insects.

5. Conclusions

Hemipteran species such as *Maiestas dorsalis*, *Nilaparvata lugens*, *Sogatella furcifera*, and *Scotinophara* sp. are significant rice pests, particularly in Southeast Asia. They are most prevalent during the late vegetative and early reproductive stages of rice growth, with their presence starting early in the planting season. To effectively control these pests and minimize economic losses, it is crucial to understand the population dynamics of hemipterans. Monitoring their population levels and implementing

appropriate management strategies can help safeguard rice crops from the damage they cause. Additionally, adapting agricultural practices at the farm level is vital in preventing more severe pest attacks, as they are less influenced by weather factors.

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References

Abdullah T, Nasruddin A & Agus N (2017). Populations of Rice Grain Bug, *Paraeuscosmetus pallicomis*, (Hemiptera, Lygaeidae) in Weed-Free Paddy Field, Weedy Paddy Field and Paddy Dykes. *Tropical Life Sciences Research* 28(2): 1-7. https://doi.org/10.21315/tlsr2017.28.2.1.

Abdul Hakim M, Juraimi A S, Mohd Razi I, Mohamed M H & Ahmad S (2013). A Survey on Weed Diversity in Coastal Rice Fields of Seberang Perak in Peninsular Malaysia. *Journal of Animal and Plant Sciences* 23(2): 534-542

Ahmed N, Holmquist B, Nasrin S, Ali M P, Bari M N, Begum M A, Afsana N & Rabbi M F (2013). Impact of climate change on rice insect pests and their natural enemies. International Conference on Climate Change Impact and Adaptation (I3CIA-2013). Gazipur, Bangladesh: Centre for Climate Change and Sustainability Research. 15–17 November 2013. pp. 245–255

Chancellor T C B, Cook A G & Heong K L (1996). The Within-Field Dynamics of Rice Tungro Disease in Relation to the Abundance of Its Major Leafhopper Vectors. *Crop Protection* 15(5): 439-449. https://doi.org/10.1016/0261-2194(96)00002-6.

Chua T H & Mikil E (1989). Effects of Prey Number and Stage on the Biology of *Cyrtorhinus lividipennis* (Hemiptera, Miridae), a Predator of *Nilaparvata lugens* (Homoptera, Delphacidae). *Environmental Entomology* 18(2): 251–255. https://doi.org/10.1093/ee/18.2.251.

Clewer A G & Scarisbrick D H (2001). *Practical Statistics and Experimental Design for Plant and Crop Science*, John Wiley & Sons Ltd., Hoboken

Dai S & Beachy R N (2009). Genetic Engineering of Rice to Resist Rice Tungro Disease. *In-Vitro Cellular Developmental Biology-Plant* 45(5): 517-524. https://doi.org/10.1007/s11627-009-9241-7.

Das K, Nath R K, Sharma P, Upamanya G K & Brahma R (2021). Seasonal Incidence of Rice Gundhi Bug *Leptocorisa oratorius* Fab. (Hemiptera, Alydidae) And Effect of Various Abiotic Factors on Their Incidence in Dhubri District of Assam. *The Pharma Innovation Journal* 10(12): 1968-1971

DOA (Department of Agriculture of Malaysia) (2022a). *Statistik Tanaman (Sub-Sektor Tanaman Makanan)*. Unit Perangkaan Pertanian, Bahagian Perancangan Strategik. Jabatan Pertanian Semenanjung Malaysia.

DOA (Department of Agriculture of Malaysia) (2022b). Rice Check Padi- Edisi 2022. Jabatan Pertanian Malaysia.

Duman M & Mutlu C (2019). Efficacy of different sampling methods in pest monitoring of direct seeded rice at different growth stages. *Applied Ecology & Environmental Research* 17(4): 10207- 10220

Elzinga R J (2004). *Fundamentals of Entomology*, 6th Edition, Pearson/Prentice Hall.

Faruq M, Khan M, Rahman M & Ullah M (2018). Rice Growth Stages and Temperature Affect the Abundance of Leafhoppers and Plant Hoppers. *SAARC Journal of Agriculture* 16(1): 95-104. https://doi.org/10.3329/sja.v16i1.37426.

Gullan P J & Cranston P S (2014). *The Insects, An Outline of Entomology*, India, Wiley.

Gurr G M (2009). Prospects for ecological engineering for planthoppers and other arthropod pests in rice. Planthoppers: New threats to the sustainability of intensive rice production systems in Asia pp. 371-388

Hashim N A, Aziz M A, Basari N, Saad K, Jasmi A H & Hamid S A (2017). Diversity And Guild Structure of Insects During Rice Flowering Stage at A Selected Rice Field in Penang, Malaysia. *Malaysian Applied Biology* 46(3): 161–169

Hegazy F, Hendawy E, Mesbah I & Salem F (2021). The Insect Pests, the Associated Predatory Insects and Prevailing Spiders in Rice Fields. *Journal of Plant Protection and Pathology* 12(5): 365-371. doi: 10.21608/jppp.2021.171281.

Heong K L & Hardy B (2009). *Planthoppers, New Threats to the Sustainability of Intensive Rice Production Systems in Asia*, IRRI Books, International Rice Research Institute (IRRI).

Heinrichs E A (2004). *Rice-feeding Insects and Selected Natural Enemies in West Africa, Biology, Ecology, Identification*, Philippines, International Rice Research Institute

Jayanthi P E & Bambaradeniya C N B (2006). Rice Fields, an Ecosystem Rich in Biodiversity. *Journal of The National Science Foundation of Sri Lanka* 34(2): 57-71. doi: 10.4038/JNSFSR.V34I2.2084.

Jauharlina J, Hasnah H, Ikram M & Taufik D (2019). Diversity and Community Structure ff Arthropods on Rice Ecosystem. *AGRIVITA Journal of Agricultural Science* 41(2): 316-324. https://doi.org/10.17503/agrivita.v41i2.2160.

Johnson N F & Triplehorn C A (2020). *Borror and Delong's Introduction to the Study of Insects*, United States, Cengage Learning.

Khare V K, Prakash R & Sneha G K (2020). Effect of Abiotic Factors on the Population Dynamics of Paddy Earhead Bug, *Leptocorisa oratorius* F. *Journal of Entomology and Zoology Studies* 8(6):157-160. DOI: 10.22271/j.ento.2020.v8.i6b.8315.

Krishnaiah N V, Lakshmi V J, Pasalu I C, Katti G R & Padmavathi C (2008). Insecticides in Rice—IPM, Past, Present and Future, *Technical Bulletin No 30 Directorate of Rice Research*, ICAR, Hyderabad

Kritsky G & Young F N (2011). *A Survey of Entomology*, United States, iUniverse.

Luo Y, Fu H & Traore S (2014). Biodiversity Conversation in Rice Paddies in China, toward Ecological Sustainability. *Journal of Sustainability* 6(9): 6107-6124. https://doi.org/10.3390/su6096107.

Mariana A, Ho T, Lau T, Heah S & Wong A (2009). Distribution of Arthropods in Rice Grains in Malaysia. *Asian Pacific Journal of Tropical Medicine* 2(5): 1-7

Masika F B, Masanza M, Aluana G, Barrigossi J A F & Kizito E B (2017). Abundance, distribution and effects of temperature and humidity on arthropod fauna in different rice ecosystems in Uganda. Journal of Entomology and Zoology Studies 5: 964-973

Mir M S, Saxena A, Kanth R H, Raja W, Dar K A, Mahdi S S, Bhat T A, Naikoo N B, Nazir A, Amin Z, Mansoor T, Myint M Z, Khan M R, Mohammad, I., & Mir, S. A. (2022). Role of Intercropping in Sustainable Insect-Pest Management: A Review. International Journal of Environment and Climate Change, 12(11): 3390–3403. https://doi.org/10.9734/ijecc/2022/v12i111390

Moir M L & Brennan K E C (2007). Using bugs (Hemiptera) as ecological and environmental indicators in forest ecosystems. *Forest Ecology Research Horizons. Nova, New York* pp. 203-238

Mutlu Ç, Duman M, Karaca V, Bayram Y & Süer İ E (2016). The species of Cicadellidae, Cixiidae and Delphacidae (Hemiptera) on Karacadag rice and the effects of weeds on their populations. *Turkish Entomology Bulletin*, 6(4): 279-289

Norazliza R, Fauziah I, Mohd Rasdi Z, Fairuz K & Ismail R (2014). Comparison and Relationship between Water Parameters and Abundance of Insects in Field and Irrigation System of Paddy Area of Sungai Burong, Tanjung Karang, Selangor, Malaysia. *Agriculture, Forestry and Fisheries*, 3(4), 249-256. https://doi.org/10.11648/j.aff.20140304.16.

Norela S, Anizan I, Ismail S & Abdullah M (2013). Diversity of Pest and Non-Pest Insects in an Organic Paddy Field Cultivated Under the System of Rice Intensification (SRI), A Case Study in Lubok China, Melaka, Malaysia. *Journal of Food Agriculture & Environment* 11: 2861-2865

Pathak M D & Khan Z R (1994). *Insect Pests of Rice*, Philippines, International Rice Research Institute

Preetha G, Stanley J, Suresh S & Samiyappan R (2010). Risk Assessment of Insecticides Used in Rice on Miridbug, *Cyrtorhinus lividipennis* (Reuter), The Important Predator of Brown Planthopper, *Nilaparvata lugens* (Stal.). *Chemosphere* 80(5): 498-503. https://doi.org/10.1016/j.chemosphere.2010.04.070.

Raj Kumar K C, Kafle K, Subedi R, Bishwas K C, Sapkota B & Shahi S (2018). Effects of Various Weather Factors in Seasonal Variation of Insects Pest in Rice in Sundar Bazar, Lamjung. *International Journal of Research in Agricultural Sciences* 5(4): 200-204

Razali R, Yaakop S, Abdullah M, Ghazali S Z & Zuki A A (2015). Insect species composition in an under SRI management in Tanjung Karang, Selangor, Malaysia. *Malaysian Applied Biology* 44(4): 59-66

Reissig W H, Heinrichs S E A & Valencia S L (1982). Effects of Insecticides on *Nilaparvata lugens* and Its Predators: Spiders, *Microvelia atrolineata* and *Cyrtorhinus lividipennis* (Reuters). *Environmental Entomology* 11(1): 193–199. https://doi.org/10.1093/ee/11.1.193.

Reissig W H (1985). *Illustrated Guide to Integrated Pest Management in Rice in Tropical Asia*. Philippines, International Rice Research Institute.

Schuh R T & Slater J A (1995). *True bugs of the world (Hemiptera: Heteroptera): classification and natural history*. Cornell University Press.

Shepard B M, Barrion A T & Litsinge J A (1987). *Friends of the Rice Farmer- Helpful Insects, Spiders, and Pathogens*, International Rice Research Institute. Los Baños, Laguna, Philippines.

Shepard B M, Barrion A T& Litsinger J A (1995). *Rice-feeding Insects of Tropical Asia*, Philippines, International Rice Research Institute.

Southwood T (2013). *Ecological Methods, With Particular Reference to the Study of Insect Populations*, Germany, Springer Netherlands.

Tan B T, Fam P S, Firdaus R B R, Tan M L & Gunaratne M S (2021). Impact of Climate Change on Rice Yield in Malaysia. *A Panel Data Analysis Agriculture* 11(6): 569-587. https://doi.org/10.3390/agriculture11060569.

Van den Berg H & Soehardi M (2000). The Influence of the Rice Bug *Leptocorisa oratorius* on Rice Yield. *Journal of Applied Ecology* 37(6): 959–970

Wada T & Nik Mohd Noor N S (1992) Population Growth Pattern of the Rice Planthoppers, *Nilaparvata lugens* and *Sogatella furcifera*, in the Muda Area, West Malaysia. *Japan Agricultural Research Quarterly* 26: 105-114.

Wang Z, Yang H, Wang X J & Jin D C (2011). Population Dynamics of *Cyrtorhinus lividipennis* (Reuter) in Karst Rice-planting Areas in Guizhou. *Chinese Journal of Biological Control* 27(4): 464-469

Wei J, Jia D, Mao Q, Zhang X, Chen Q, Wu W, Chen H & Wei T (2018). Complex Interactions between Insect-Borne Rice Viruses and Their Vectors. *Current Opinion in Virology* 33: 18–23. https://doi.org/10.1016/j.coviro.2018.07.005.

Wilson M R & Claridge M F (1991). *Handbook for the Identification of Leafhoppers and Planthoppers of Rice*. Wallingford: CAB International. 142 pp

Win S S, Muhamad R, Ahmad Z A & Adam N A (2011). Life table and population parameters of *Nilaparvata lugens* Stal. (Homoptera: Delphacidae) on rice. *Tropical Life Sciences Research* 22(1): 25-35

Xiao Z, Xu Q, Lu W & Liu F (2014). Sublethal Effects of Four Synthetic Insecticides on the Generalist Predator *Cyrtorhinus lividipennis*. *Journal of Pest Science* 88(2): 383-392. https://doi.org/10.1007/s10340-014-0606-2.

Yaakop S, Sabri S, Kamaruddin N A' K, Norizam N N & Mohammed M A (2022). Species Composition and DNA Barcoding of Hemipteran Assemblages Throughout Paddy Growing Seasons. *Pertanika Journal of Tropical Agricultural Science* 45(3): 631-648. https://doi.org/10.47836/pjtas.45.3.06.

Yang X, Huang J, Liu C, Chen B, Zhang T & Zhou G (2017). Rice Stripe Mosaic Virus, a Novel Cytorhabdo Virus Infecting Rice via Leafhopper Transmission. *Frontiers in Microbiology* 7: 1-13. https://doi.org/10.3389/fmicb.2016.02140.

Zhou G, Wen J, Cai D, Li P, Xu D & Zhang S (2008). Southern Rice Black-Streaked Dwarf Virus, a New Proposed Fiji Virus Species in the Family Reoviridae. *Chinese Science Bulletin* 53(23): 3677-3685. https://doi.org/10.1007/s11434-008-0467-2.

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Welfare Effects of Food Tariff Changes on Urban and Rural Households

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ABSTRACT
This study aims to analyze the effects of food tariff changes on the welfare of urban and rural households in Iran. The study considers the role of households as consumers, producers, and workers, as well as the market structure over the past fifteen years. Firstly, the study estimated the consumption behavior for the main food groups using the QUAIDS and pseudo-panel data. Then, the extent of tariff pass-through to domestic food prices was determined, and after that, price-wage elasticity and wage changes as a result of tariff changes were estimated. Finally, it calculated the effect of tariff changes on household purchasing power and income through an indirect utility function to get welfare effects. The results indicate that tariff pass-through to food prices is incomplete and varies between urban and rural areas. The study has found that skilled labor is more sensitive to food tariff reductions than unskilled labor, particularly in rural areas. The results reveal that tariff changes positively affect urban households' welfare, while rural households experience a loss due to these changes. Urban areas benefit from reduced household expenditure, while food prices are increasing in rural areas due to weak or absent tariff pass-through. Although these increases favor producers, they do not compensate for the loss consumers suffer, resulting in reduced welfare in rural areas. The findings show that the effects of tariff changes vary across regions, not only between urban and rural areas but also among different provinces. Furthermore, the tariff reductions have been a boon for consumers, but a bane for producers, ultimately harming production in the long term. The findings suggest that regional markets may be either sufficient or insufficient to convert pass-through-the-border prices into domestic prices. Therefore, policymakers can use this study as a useful guide to reform the regional market structure to raise household welfare, food security, and income inequality.

Keywords: Food Demand, Pseudo-Panel Data, Welfare effect, Wage, Tariff

1. Introduction

As the world's population grows, feeding everyone is becoming a significant concern for many governments. To address this challenge, countries increasingly seek to expand their trade relations internationally. This trend has been ongoing for the past two decades. The history of international trade theories and integration into the global economy dates back to Adam Smith's absolute advantage theory. In his book Wealth of Nations, Smith argued that a market's invisible hand, rather than government policy, determines what a country imports and exports. In 1817, David Ricardo criticized an idea Heckscher and Ohlin later challenged in 1919 and 1933. They introduced the theory of comparative advantage in international trade. According to classical theory, trade liberalization benefits everyone. Workers can quickly move from the competitive import sector to the expanding export sector, so there is no need to adjust wages for full employment. Samuelson & Stolper (1941) developed this theory based on Heckscher and Ohlin's theory. According to Samuelson and Stolper's theory, trade liberalization benefits the abundant factors and harms the scarce factors (Husted & Melvin 2012). Therefore, unskilled labor should benefit from trade liberalization in developing countries with a large amount of unskilled labor. It is worth noting that various economic theories are based on unrealistic assumptions, so their theoretical predictions only sometimes come true in real-world scenarios. For instance, Chao et al. (2019) discovered that tariff reductions can temporarily narrow the wage gap between skilled and unskilled labor. However, the long-term effect on wage inequality could be more favorable. Murakami (2021) also found that while effective tariff reductions may increase industry wages, they only benefit skilled workers, exacerbating wage inequality. Additionally, Dhamija (2023) demonstrated that trade openness does not necessarily decrease wage inequality in Indian rural areas and states. On the other hand, urban wage inequality is increasing due to trade openness. Hyun-Jung et al. (2024) revealed that at a low level of trade openness, an increase exacerbates income inequality, whereas at a high level, trade openness can contribute to decreased income inequality.

Trade liberalization has been a popular strategy for many developing countries in the last two decades. Economic theory suggests that it leads to an overall increase in the country's welfare. However, the effects of trade liberalization on the economy are still a topic of debate. Several studies (e.g., Cho & Diaz 2010; Taylor et al. 2010; Hossain 2011; Marchand 2019; Muñoz et al. 2020; Topuz & Dağdemir 2020; Sethi et al. (2021); Rosenfeld et al. (2024); Tabash et al. 2024) have investigated the effects of trade liberalization on developing countries and produced varying results, although the results were inconclusive. Rojas-Vallejos & Turnovsky (2017) examined 37 countries and found that reducing is likely to lead to greater income inequality in the long run. Shinyekwa et al. (2021), which focused on the East African Community (EAC) countries, found that the African Continental Free Trade Agreement had mixed effects. While all EAC countries experienced tariff revenue losses, the welfare effects varied among these countries, so Uganda and Burundi saw positive effects, while Kenya, Tanzania, and Rwanda saw negative effects. Naanwaab (2022) indicated that while trade liberalization leads to a decrease in income inequality, its effects depend on the direction of trade. Rosenfeld et al. (2024) demonstrated that with trade openness, economic simplification reduced income inequality in Latin American countries. Similarly, Tabash et al. (2024) observed this trend in 18 developing countries.

The distribution of social benefits is an important political issue that arises when it comes to improving general welfare. One of the main goals of economic policy is to enhance the welfare of low-income households. Nicita (2004; 2009) demonstrated that trade liberalization had benefited Mexico. Still, it has also contributed to inequality among regions, such as urban and rural areas, south and north, and skilled and unskilled workers. Recent debates on the impact of trade liberalization on welfare have highlighted the need to identify this policy's actual beneficiaries and losers. Marchand (2012) found that all households, regardless of their per capita expenditure, benefit from trade liberalization, and the effect of trade liberalization is generally pro-poor. Similarly, Silva & Krivonos (2021) in Peru found that while wages for poorly educated and well-educated workers declined due to openness to trade, self-employed workers were strongly affected. This resulted in unskilled workers benefiting the most from the trade liberalization.

It is essential to determine how tariff changes affect household welfare, considering that families play both the roles of consumers and producers. Therefore, it is necessary to investigate the potential channels through which policy changes may affect households. If the market can transmit price changes from the global markets to the consumer, tariff reductions will decrease domestic prices, increasing consumer welfare. However, market failure may lead to an incomplete pass-through. Whether households will benefit from trade liberalization depends on the structure and efficiency of the market where goods are produce13d and sold. In other words, the effect of tariff reduction on the economy depends on the amount of tariff reduction and the extent to which it is passed down to domestic prices. These shocks affect the entire economy by changing relative prices. Price changes are essential in reallocating resources, income distribution, and poverty. In Ghana, Mensah (2019) found that trade liberalization negatively affects rural farm households' income and consumption spending while it benefits urban non-farm households. Vo & Nguyen (2021) indicated that trade liberalization enhances Vietnamese household income and expenditure through either the export channel or increased labor demand. Tariff reduction for exported goods is less favorable to household welfare. Vellinga & Tanaka (2024) demonstrated that trade liberalization results in household welfare converging at a higher level in the long run rather than the short run. The impact of trade liberalization on household welfare has been extensively discussed in the literature by various scholars (e.g., Seshan 2014; Okodua 2014; Le 2014; Han et al. 2016; Bansah & Mohsin 2021; Vo & Nguyen 2021; Wang et al. 2024). Empirical studies have shown that the welfare effects of trade liberalization are influenced not only by tariff reductions but also by other factors such as household characteristics (e.g., size and expenditure patterns) and individual and market characteristics (e.g., price stability and labor market infrastructure) (Nicita 2004, 2009). Therefore, it is evident that the distribution effects of trade liberalization vary across countries and need to be analyzed on a case-by-case basis. Khan et al. (2021) suggested that trade liberalization can improve household income equality and benefit agriculture but may lead to a decline in urban and non-farm household income. Whereas, Murakami (2021) suggests that higher import competition resulting from decreases in output tariffs leads to skill enhancement within industries, consequently increasing the demand for skilled workers.

This study concentrates on the major commodities that comprise a household food basket, covering chapters 2-4, 7-8, 10-11, 15-17, and 19-21, categorized by the Tariff Harmonized System (HS) Codes. We classified these items into six groups: 1-cereal, 2-meat, 3-dairy, 4-oils and fats, 5-fruit, vegetables, and pulses, and 6- sugar. These categories are considered sub-sectors of the agriculture sector, as they are the main items of a household food basket. Therefore, this study will analyze the effects of tariff changes on these food groups to determine how much trade policy affects household welfare, especially changes in agriculture and food import tariffs. A household's choice of food is contingent on the proportion of income required to buy food. In developing countries, households spend much of their income on food. According to the 2022 Iranian household budget survey, the average annual gross expenditure for urban and rural households was 1.397 and 0.809 billion Rials. Food groups accounted for 26.9% and 40.6% of this expenditure. Food accounts for a significant portion of household expenditure in Iran's urban and rural areas. However, the percentage of food expenditure varies between different provinces. In urban households, food expenses range from 10% in Qom province to 41% in Kohgiluyeh and Boyer Ahmad provinces. In rural areas, it varies from 22% in Tehran to 59% in Sistan and Baluchistan province. This indicates that consumption patterns and food expenses differ across different regions of Iran. Considering that Iran is yet to become a member of the World Trade Organization (WTO) and has not implemented trade liberalization on a large scale, it is an ideal time to study the distribution effects, benefits, and costs of trade liberalization before expanding trade relations globally. Therefore, this study aims to examine the welfare effects of food tariff changes on urban and rural households in Iran. In this context, three hypotheses will be considered. First, reducing food tariffs

is expected to lower domestic food prices in urban and rural areas. Second, alterations in food tariffs influence wages and income inequality. The third hypothesis posits that changes in food tariffs substantially affect the welfare of urban and rural households.

2. Material and Methods

2.1. Data collection

The required data for this study included a wide range of statistics that have been collected from various sources, such as Export and Import Regulations Yearbooks, Statistical Center of Iran, Central Bank of the Islamic Republic of Iran, Islamic Republic of Iran Customs Administration (IRICA), FAO and World Bank for the period of 2006-2020. This data has been gathered separately for all urban and rural areas. The household information data includes the raw data of the Statistics Center of Iran as "Household Expenditure and Income" survey data in the period of 2006-2020, which was collected for the urban and rural areas separately for 32 provinces of Iran. In this study, the Deaton (1985) method has been used to build the pseudo-panel data. This method is used because a time series of household survey data does not exist (for a given household over time). Deaton claims that it is possible to construct pseudo-panel data using repeated cross-sectional data (with entirely different instances) and estimators derived from similar panel data. In this way, each cohort is created from individuals who share some characteristics; then, observations are constructed from the mean of each cohort.

In 2022, the value of Iran's imports was equal to $5969 million, of which 24% ($14101 million) is related to the agriculture sector (IRICA 2022). Tariff changes for the six groups including: 1-cereal, 2-meat, 3-dairy, 4-oils and fats, 5-fruit, vegetables, and pulses, and 6- sugar are shown in Figure 1 during 2006-2020. As shown in Figure 1, tariffs for almost all groups decreased during these years, especially after 2016.

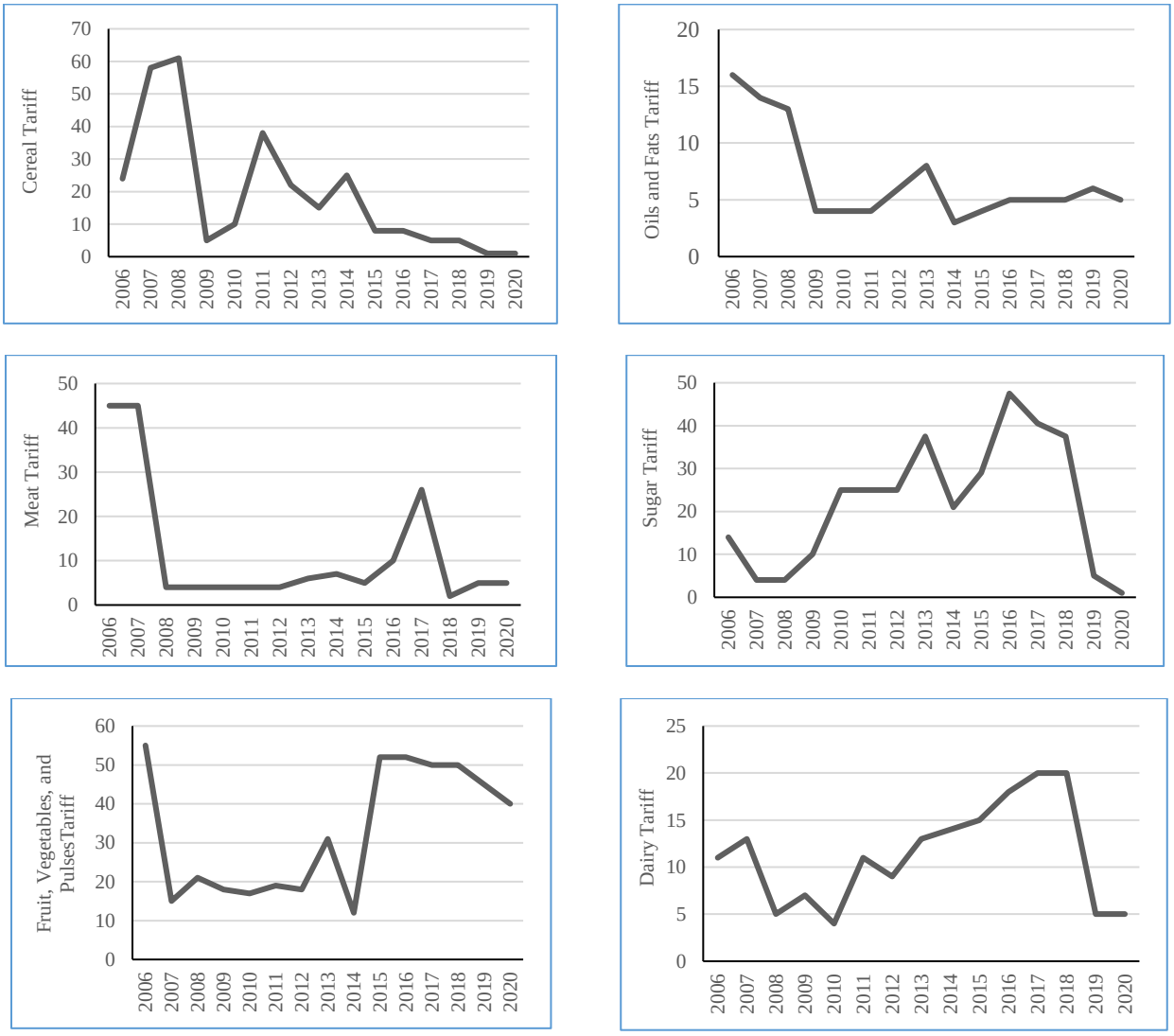

Figure 1- Tariff changes of selected food groups in Iran from 2006 to 2020. Source: Import and export regulations and annexed tables books (2006-2020), and the Islamic Republic of Iran Customs Administration (IRICA) (2020)

2.2. Methods

According to economic theory, changes in tariffs impact prices and wages. In this study, we analyze how households respond to changes in prices and income resulting from modifications in tariffs while also considering their heterogeneity. First, it is necessary to separate the effect of tariff changes on domestic prices from the impact of other policies, such as exchange rates. Then, we can calculate the changes in prices resulting from tariff changes. Next, we need to estimate an income equation to determine how changes in prices affect wages. Finally, we gather the effects of tariff changes on purchasing power and income in an indirect utility function to obtain the welfare effects. A household's indirect utility function can be expressed as follows:

$$u_h = V_h[y_h . P] \tag{1}$$

Household utility (u_h) is expressed as a function of the vector of prices (P), paid by households for goods and services, and household income (y_h). Change in a household's welfare can be obtained through approximation of a second-order Taylor series expansion as Equation 2.

$$\frac{du_h}{y_h} = \sum_s \theta_h^s \, dw_r^s + \sum_u \theta_h^u \, dw_r^u + \sum_g \theta_{hg}^x \, dp_{gr} - \sum_g \theta_{hg}^c dp_{gr} - \sum_g \eta_{hg} \theta_{hg}^c dp_h - \frac{1}{2}\left(\sum_g \varepsilon_g \theta_{hg}^c dp_{gr}^2 + \sum_g \sum_{k \neq g} 2\varepsilon_{hgk} \theta_{hg}^c dp_{gr} dp_{kr} \right) \tag{2}$$

Where; η_{hg} is expenditure elasticity, ε_g, own-price elasticity, ε_{hgk}, the cross-price elasticity of good *g* to good *k*, θ_h^s and θ_h^u, skilled and unskilled labor income share, θ_{hg}^x, the share of income from the sale of goods *g* by household *h*, θ_{hg}^c, expenditure share on good *g* by household *h*, and dw_r^s, dw_r^u, dp_{gr}, changes in skilled and unskilled wages and prices respectively (Nicita 2004; 2009).

Choosing an appropriate and flexible demand system is essential when estimating own-, cross-price, and expenditure elasticities. The Almost Ideal Demand System (AIDS) and the Quadratic Almost Ideal Demand System (QUAIDS) are the most commonly used demand systems in the literature, as they are consistent in modeling consumer behavior and flexible in representing consumer expenditure patterns. The QUAIDS is an extension of the AIDS model that includes a higher-order expenditure term to estimate the nonlinear Engel curve, but this does not necessarily make it superior to the AIDS model. Therefore, the Wald test is used to determine the most suitable functional form.

Following Poi (2012), Lopez et al. (2022), and Echeverría & Molina (2022) which investigated the effects of household characteristics on food demand, this study also utilizes the QUAIDS model to describe expenditure share and prices of the different food groups while taking into account social and regional characteristics of households as Equation 3:

$$w_{iht} = \alpha_i + \sum_{j=1}^{n} \gamma_{ij} \, ln \, p_{jht} + (\beta_i + \acute{\eta}_\iota z) \, ln \left[\frac{y_{ht}}{\bar{y}_0(z) f(p)} \right] + \frac{\lambda_i}{g(p) c(p.z)} \left\{ ln \left[\frac{y_{ht}}{\bar{y}_0(z) f(p)} \right] \right\}^2 \tag{3}$$

Where; w_{iht} and p_{jht} are expenditure share and price of good *i* in the household *h* in time *t*, y_{ht} is the expenditure of the goods in each household at time *t*, and $f(p)$, $g(p)$are price functions as $log\, f(p) = \alpha_0 + \sum_{i=1}^{n} \alpha_i \, log \, p_i + \frac{1}{2} \sum_{i=1}^{n} \sum_{j \neq i} \gamma_{ij} \, log \, p_i \, log \, p_j$ and $log \, g(p) = \beta_0 + \sum_{i=1}^{n} \beta_i log p_i$. *z* is a vector of household characteristics variables, including household size, education of head of household, and age-gender ratio series. This ratio is made by dividing the number of people in each age category by the total number of households. For this purpose, individuals are divided by gender and three age groups: youth (0-14 years old), adults (15-64 years old), and elderly (over 65 years old); therefore, up to six variables determine the age-gender ratio series. Also, since the demand style differs across different regions, a region of residence's dummy variable is added to the model. $\bar{y}_0(z)$ represents an increase in household expenditure as a function of *z*, $c(p.z) = \prod_{j=1}^{n} p_j^{\eta_j z}$, and α, β, γ, η, λ are parameters that should be estimated.

Uncompensated price elasticity of good *i* concerning changes in the price of good *j* (ε_{ij}) and expenditure elasticity for good *i* (μ_i) in the QUAIDS model with household characteristics variables are as Equations of 4 and 5.

$$\varepsilon_{ij} = -\delta_{ij} + \frac{1}{w_i}(\gamma_{ij} - \left[\beta_i + \acute{\eta}_i z + \frac{2\lambda_i}{g(p) c(p.z)} \ln \left\{ \frac{y}{\bar{y}_0(z) f(p)} \right\} \right] \times (\alpha_j + \sum_i \gamma_{ji} \ln p_i) - \frac{(\beta_j + \acute{\eta}_j z)\lambda_i}{g(p) c(p.z)} \left(\left[\ln \left\{ \frac{y}{\bar{y}_0(z) f(p)} \right\} \right]^2 \right) \tag{4}$$

$$\mu_i = 1 + \frac{1}{w_i}\left[\beta_i + \acute{\eta}_i z + \frac{2\lambda_i}{g(p)c(p.z)} \ln\left\{\frac{y}{\bar{y}_0(z)f(p)}\right\}\right] \quad (5)$$

Compensation price elasticities are calculated with the *Slutsky* equation as $\varepsilon_{ij}^{C} = \varepsilon_{ij} + \mu_i \omega_j$ (Poi 2012; Echeverría & Molina 2022).

2.3. Tariff Pass-through to prices

In general, the theory of tariff pass-through draws heavily from the extensive literature on exchange rate pass-through, which examines how changes in exchange rates affect the prices of imported goods. An incomplete exchange rate transfer means that the exporter will absorb some of the exchange rate changes as a markup for the final cost (Campa & Goldberg 2002). A tariff pass-through model identifies the extent to which observed price changes can be directly related to a change in tariff policy. Factors such as market imperfections and trade costs prevent the complete transmission of tariff changes to domestic prices.

Nicita (2009) extended the approach of Porto (2006) by adding a link from trade policy to domestic prices. To analyze the effect of tariff changes on prices, Nicita (2004; 2009) suggests that changes in the domestic price of imported goods are specified by multiplying tariff change by the imported reasonable price and adjusted by exporter markup changes. Based on this, the cost of trade is used to calculate the reception of border price changes by local markets as Equation 6:

$$\mathrm{P_{gtr}} = \mathrm{e_t PX^{*}_{gt}}\left(1+\tau_{\mathrm{gt}}\right)\mathrm{TC_{gtr}} = \mathrm{e_t}(\phi_{\mathrm{gtr}}\mathrm{CP^{*}_{gt}})(1+\tau_{\mathrm{gt}})\mathrm{TC_{gtr}} \quad (6)$$

Where; P_{gtr} is the domestic price of imported good g in time t in region r, e_t, exchange rate, τ_{gt}, tariff, TC_{gtr}, trade costs, PX^{*}_{gt} , the global price that is equal to the cost of producing goods (CP^{*}_{gt}) multiplied by the markup $\phi_{\mathrm{gtr}} = \left(\frac{\mathrm{PD_{gtr}}}{\mathrm{CP^{*}_{gt}e_t}(1+\tau_{\mathrm{gt}})\mathrm{TC_{gtr}}}\right)^{\alpha}$, where PD_{gtr} is the price of imported competitive products in region r. Thus, we can rewrite the P_{gtr} as Equation 7:

$$\mathrm{P_{gtr}} = \left(\frac{\mathrm{PD_{gtr}}}{\mathrm{CP_{gt}}\left(1+\tau_{\mathrm{gt}}\right)\mathrm{TC_{gtr}}}\right)^{\alpha} \mathrm{CP_{gt}}\left(1+\tau_{\mathrm{gt}}\right)\mathrm{TC_r}\ , \quad 0 \le \alpha \le 1 \quad (7)$$

Where; α is a parameter that can be considered as the level of competition in the domestic market. By taking logarithms from Equation (7), Equation (8) is obtained.

$$\ln \mathrm{P_{gtr}} = \alpha \ln \mathrm{PD_{gtr}} + (1-\alpha)\ln \mathrm{CP_{gt}} + (1-\alpha)\ln\left(1+\tau_{\mathrm{gt}}\right) + (1-\alpha)\ln \mathrm{TC_{gtr}} \quad (8)$$

Where; $1-\alpha$ expresses the coefficient of pass-through; according to pass-through literature, Equation (8) can be written as Equation (9). This equation uses distance d as a measure of the cost of trade since it represents the shortest distance from the center of each region (e.g. province) and the border at which goods enter the nation.

$$\begin{aligned} Ln\,P_{gtr} &= \beta_0 + \beta_1 Ln\,X_{gt} + \beta_2 Ln\,Z_{gtr} + \beta_4 d_r + \gamma Ln(1+\tau_{tg}) + \gamma_1 Ln[(1+\tau_{tg})d_r] \\ &\quad + \gamma_2[Ln(1+\tau_{tg})d_r]^2 + \mu_r + \eta_t + \varepsilon_{gtr} \end{aligned} \quad (9)$$

Where; X_{gt}, as a proxy for CP_{gt}, is the control variable that involves the global commodity prices of good g in domestic currency, and Z_{gtr} as the proxy for competitive imported products price (PD_{gtr}). Z_{gtr} is the vector of control variables, including *i)* the local supply ($S_{gtr} = \frac{\sum_h P_{hrgt}}{\sum_h P_{hrt}}$), where is the production of good g at time t in region r in household h, *ii)* regional income ($RI_{tr} = \frac{\sum_h Y_{hrt}}{H_{rt}}$), where is household expenditures h in region r, at time t, H_{rt} is the number of households in region r at time t, and *iii)* the Producer Price Index (PPI) of agricultural production as the proxy for the producer inflation rate. μ_r and η_t represent region and time fixed effects respectively, $\varepsilon_{\mathrm{gtr}}$ is i.i.d error term. To control time-varying factors, the year fixed effects are included in the model for all regions, and regional fixed effects are included for regional price differences. Parameter $\gamma = 1-\alpha$ is pass-through elasticity, and γ_1 is adjusted for each region. If $\gamma = 1$, pass-through is complete, and pass-through is imperfect if $\gamma < 1$. $\gamma_1 = 0$ indicates that pass-through is the same in all regions and $\gamma_1 \neq 0$ when regional prices vary with tariff change.

Deaton's (1985) method and the pseudo-panel data were used to estimate Equation 9. Time series and repeated cross-sectional data (surveys given to different interviewees at different time points) were combined to create pseudo-panel data. Each cohort was made using individuals who share common characteristics, and then the average of each cohort was recorded. This method

was used because time series household survey data do not exist. After estimating Equation (9), the percentage of price changes is calculated as follows:

$$dp = \frac{\hat{P}_{gt_1r} - \hat{P}_{gt_0r}}{\hat{P}_{gt_0r}} \quad (10)$$

Where; $\hat{P}_{gt_1r}$ is the predicted price for the last year, and $\hat{P}_{gt_0r}$ is the predicted price for the first year, which is captured from Equation (9).

2.4. Price-Wage elasticities

To calculate Equation (2), estimating the percentage of wage changes is necessary (dw_h). According to Nicita (2009), the income of each household can be illustrated by Equation (11).

$$\ln w_{ijt} = \sum_{grs} \theta^r \theta^s \ln p_{ij}^{gr} \beta_{ij}^{grs} + Z_{it}\gamma + H_{jt}\delta + \varepsilon_{ijt} \quad (11)$$

Where; w_{ijt} is observed wages for a person *i* in household *j* at time *t*, p_{ij}^{gr}, price of good *g* that person *i* must pay in household *j* in region *r*, Z_i, a vector of individual characteristics, H_j, a vector of household characteristics, $\theta^r$and θ^s are dummy variables for workers residence and skills, respectively, ε_{ijt}, the error term, and β_{ij}^{grs}. γ and δ are coefficients that must be estimated. The model also includes several control variables, like as age, years of education, labor gender, occupation status of household head, type of employment, and a regional dummy variable. The region variable controls for the influence of geographic regions (the dummy variable takes the value one if an individual is a resident of province *r* and zero otherwise). The model is estimated for all 18- to 65-year-olds who have declared their salary.

In Equation (11), the dependent variables are individual wages (and not average wages), and the prices may be endogenous to wages. So, after running an exogenous test, the instrumental variables are applied if the prices are endogenous. Additionally, all food groups are aggregated into a single group using their expenditure shares to reduce multi-collinearity. Finally, the percentage changes in wages (dw_h) are calculated by Equation (12):

$$dw_{hrt}^{s,u} = \sum_g \beta_{grt}^{s,u}\, dp_{ghrt} \quad (12)$$

Where; β_g is price-wage elasticity for good *g*, and dp_{gh} is the percentage change in prices that households must pay.

3. Results and Dissection

3.1. Estimation of price and expenditure elasticities

To choose a proper demand system from among the AIDS and QUAIDS, the Wald test was conducted. The chi-square statistics were calculated for urban and rural household demands, resulting in 608.84 and 63.79, respectively, which were significant at 1% probability. Therefore, the QUAIDS model was chosen as the appropriate model, and Equation (3) was estimated for six food groups by resolving heteroskedasticity separately for both urban and rural areas. The results of estimating the QUAIDS model are presented in Appendix Table A. Table 1 shows urban and rural areas' price and expenditure demand elasticities.

Table 1- Estimating expenditure, uncompensated and compensated price elasticity for urban and rural areas

	Cereal		*Meat*		*Dairy*		*Oils and Fats*		*Fruit, Veg.& Pulses*		*Sugar*	
	Urban	*Rural*	*Urban*	*Rural*	*Urban*	*Rural*	*Urban*	*Rural*	*Urban*	*Rural*	*Urban*	*Rural*
Expenditure Elasticity	0.8 (0.09)	0.76 (0.11)	1.2 (0.10)	1.17 (0.05)	0.93 (0.03)	0.86 (0.12)	1.04 (0.01)	1.22 (0.25)	1.01 (0.00)	0.98 (0.16)	1.07 (0.04)	1.54 (0.39)
Uncompensated price elasticity												
Cereal	-0.71 (0.02)	-0.87 (0.01)	-0.20 (0.02)	0.05 (0.01)	0.05 (0.00)	-0.003 (0.00)	0.006- (0.00)	0.02 (0.00)	0.02 (0.01)	0.00 (0.01)	-0.006 (0.00)	0.01 (0.00)
Meat	-0.29 (0.02)	-0.05 (0.01)	-0.75 (0.03)	-1.02 (0.04)	0.01 (0.01)	0.11 (0.02)	0.008 (0.01)	-0.07 (0.02)	-0.11 (0.02)	-0.17 (0.03)	-0.02 (0.01)	0.004 (0.02)
Dairy	0.09 (0.02)	-0.004 (0.01)	0.09 (0.03)	0.31 (0.04)	-1.04 (0.04)	-1.04 (0.05)	0.005 (0.01)	0.06 (0.03)	0.01 (0.03)	-0.04 (0.05)	-0.10 (0.02)	-0.10 (0.02)
Oils and Fats	-0.07 (0.03)	-0.05 (0.02)	0.06 (0.47)	-0.30 (0.08)	0.0002 (0.03)	0.07 (0.06)	-0.93 (0.03)	-0.57 (0.09)	-0.10 (0.04)	-0.37 (0.08)	0.01 (0.02)	-0.09 (0.06)
Fruit, Veg. and Pulses	-0.01 (0.01)	-0.03 (0.01)	-0.7 (0.02)	-0.10 (0.03)	-0.001 (0.01)	-0.03 (0.02)	-0.02 (0.00)	-0.07 (0.01)	-0.92 (0.02)	-0.60 (0.04)	0.02 (0.01)	-0.07 (0.01)
Sugar	-0.09 (0.03)	-0.16 (0.02)	-0.09 (0.05)	-0.07 (0.10)	-0.27 (0.06)	-0.32 (0.06)	0.01 (0.02)	-0.12 (0.06)	0.12 (0.06)	-0.5 (0.09)	-0.73 (0.07)	-0.41 (0.10)
Compensated price elasticity												
Cereal	-0.49 (0.02)	-0.66 (0.021)	0.006 (0.02)	0.24 (0.01)	0.16 (0.01)	0.09 (0.00)	0.03 (0.00)	0.07 (0.00)	0.25 (0.01)	0.19 (0.01)	0.03 (0.00)	0.05 (0.00)
Meat	0.006 (0.02)	0.27 (0.01)	-0.46 (0.03)	-0.74 (0.03)	0.16 (0.01)	0.27 (0.02)	0.07 (0.01)	0.00 (0.02)	0.19 (0.02)	0.12 (0.03)	0.03 (0.01)	0.07 (0.02)
Dairy	0.33 (0.02)	0.21 (0.01)	0.32 (0.03)	0.50 (0.03)	-0.92 (0.05)	-0.94 (0.05)	0.05 (0.01)	0.11 (0.03)	0.26 (0.03)	0.15 (0.04)	-0.06 (0.02)	-0.05 (0.02)
Oils and Fats	0.18 (0.02)	0.31 (0.02)	0.32 (0.04)	0.004 (0.07)	0.12 (0.03)	0.24 (0.06)	-0.87 (0.03)	-0.49 (0.09)	0.17 (0.04)	-0.05 (0.08)	0.06 (0.02)	-0.01 (0.06)
Fruit, Veg. and Pulses	0.24 (0.01)	0.22 (0.01)	0.17 (0.02)	0.11 (0.03)	0.12 (0.01)	0.08 (0.02)	0.03 (0.00)	-0.01 (0.02)	-0.65 (0.02)	-0.37 (0.04)	0.07 (0.01)	-0.02 (0.02)
Sugar	0.18 (0.03)	0.27 (0.02)	0.17 (0.05)	0.30 (0.09)	-0.14 (0.06)	-0.12 (0.06)	0.07 (0.02)	-0.02 (0.06)	0.40 (0.06)	-0.10 (0.08)	-0.68 (0.07)	-0.32 (0.10)

*, **, and ***; indicate significant at 10%, 5%, and 1%, respectively. The amount in parentheses is a standard error.

The findings indicate that meat, oils and fats, fruits, vegetables, pulses, and sugar are luxury goods in urban areas. In contrast, meat, oils and fats, and sugar are luxury goods in rural areas. Moreover, based on expenditure elasticity, cereal and dairy are considered luxury goods in urban areas, while cereal, dairy, fruits, vegetables and pulses are considered luxury goods in rural areas. The own-price demand elasticities in urban and rural areas [in Table 1] were negative, which aligns with economic theory. Interestingly, there were differences in consumer behavior between urban and rural areas, as evidenced by the comparison of cross-price demand elasticity. As expected, the signs of compensated own-price demand elasticity were negative for rural and urban areas for all food groups. According to the Slutsky equation, the difference between compensated and uncompensated price elasticity for each group was equal to expenditure elasticity.

3.2. Estimation of tariff pass-through

To estimate Equation (9), we need to first determine the distance *d*. It is worth noting that in Iran, the ports that have imported the highest volume of food items are *Imam Khomeini Port, Amir Abad Port, Martyr Rajai Customs, Lengeh Port, Noshahr Port, Bushehr Port, Mashhad, and Martyr Bahonar* Customs. These ports are shown on Iran's map in Figure 2.

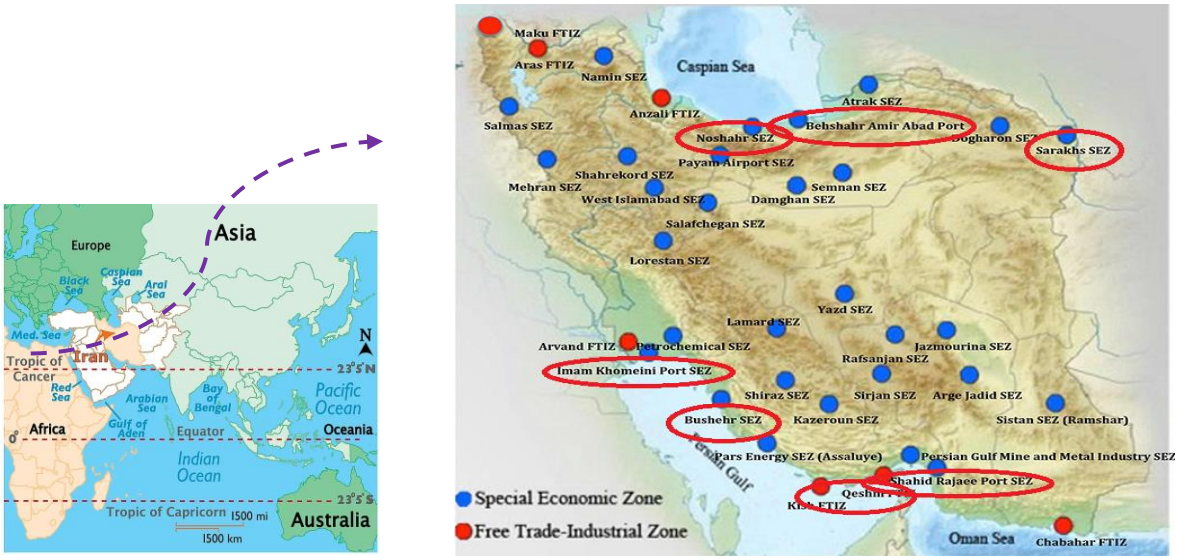

Figure 2- List of Free Trade Zones (FTIZ), Special Economic Zones (SEZ), and Main Port in Iran

The distance between each provincial center and the nearest main port was calculated, considering that the main ports of entry and customs are located across different borders (north, south, southwest, and east regions). Table 2 presents the result of the tariff pass-through model for six food categories in urban and rural areas. The GLS method was used to remove heteroscedasticity. According to economic theory, the tariff coefficient (γ) is expected to be positive, and the tariff-distance coefficient (γ_1) is expected to be negative. In urban areas, the coefficient for cereals at the border was 2.5%. Additionally, the tariff-distance coefficient for cereal was 0.032, which had the expected sign. This coefficient shows that tariff changes do not affect cereal prices at around 781 km from the nearest port ($\frac{0.025}{0.032} \times 1000$). The tariff pass-through coefficients for meat, dairy, oils and fats, fruit, vegetables, and pulses, and sugar were 9.1%, 13.1%, 16.2%, 19.2%, and 12.1%, respectively. As the borders and ports become more remote, the extension of tariff pass-through on prices for cereal, meat, fruit, vegetables, and pulses has been eased. The road tariff pass-through is negligible in urban areas, with coefficients ranging from 9.1% to 19.2%. Low values of these coefficients indicate that consumers do not benefit much from tariff changes.

As mentioned in Table 2, the tariff pass-through coefficients for these food groups range from 9.1 to 19.1% in urban areas, indicating that consumers do not benefit much from tariff changes. Moreover, increasing distances to borders and ports reduces the extent of tariff pass-through to prices. The control variables have the expected sign and the domestic prices of cereals, dairy, oils and fats, fruits, vegetables, and pulse, and sugar positively and significantly affected through their world prices in urban areas. Thus, these findings validate our initial hypothesis that reducing food tariffs results in decreased domestic food prices in urban and rural areas, which aligns with Nicita (2004; 2009), Marchand (2019), Mogendi et al. (2023), and Wang et al. (2024) findings. Additionally, the agricultural producer price index (PPI) positively and significantly impacts the prices of cereals, meat, oils and fats, fruits, vegetables, and pulses, and sugar groups. However, only oil and fats prices decreased by raising the local supply. The effects of regional income control variables indicated that in urban areas, the price of cereals, dairy products, oils and fats, and sugar decreased by 18%, 9.4%, 8.7%, and 5.1%, respectively, with a one percent increase in the regional income. Meanwhile, the prices of meat, and fruit, vegetables, and pulses increased by 3.8% and 1.7%, respectively.

The findings of tariff transfer in rural areas are presented in Table 2, with the values of tariff pass-through coefficients having the expected sign in all cases. The coefficients for meat, dairy products, fruits, vegetables, and pulses were negligible. The coefficient of the variable tariff distance in rural areas did not differ across regions, which is consistent with Nicita's (2004; 2009) findings, which noted insignificant regional differences for agricultural products in all Mexican states.

Table 2- Estimating tariff pass-through to food prices in urban and rural areas

Variables \ Product	Cereal	Meat	Dairy	Oils & fats	Fruit, veg., and pulses	Sugar
Urban Areas						
World price	0.212***	0.012	0.190***	1.78***	0.089**	0.097***
	(0.038)	(0.019)	(0.023)	(0.068)	(0.038)	(0.032)
PPI	0.263***	0.087**	0.018	0.475***	0.027	0.042*
	(0.029)	(0.038)	(0.012)	(0.058)	(0.019)	(0.023)
Local supply	0.023	0.046	-0.0018	-0.087***	0.008	-0.024
	(0.016)	(0.031)	(0.005)	(0.019)	(0.006)	(0.015)
Regional income	-0.18***	0.038	-0.094***	0.087**	0.017	-0.051***
	(.027)	(.019)	(.013)	(.041)	(.015)	(0.021)
Tariff	0.025**	0.091***	0.131***	0.162**	0.192***	0.121***
	(0.012)	(0.011)	(0.018)	(0.065)	(0.013)	(0.032)
Tariff × Distance	-0.032**	-0.067***	-0.032	-0.008	-0.039***	-0.032
	(0.013)	(0.018)	(0.024)	(0.025)	(0.013)	(0.022)
$(\text{Tariff} \times \text{Distance})^2$	1.15e-06	-8.70e-06***	7.31e-06	-3.91e-05*	1.64e-05***	2.32e-07
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Constant	6.15***	6.45***	4.86***	-7.51***	3.94***	4.73***
	(0.621)	(0.472)	(0.321)	(0.922)	(0.382)	(0.421)
Rural Areas						
World price	0.125	0.011	0.321***	0.322***	-0.128	0.065*
	(0.122)	(0.121)	(0.091)	(0.113)	(0.087)	(0.031)
PPI	0.287***	0.253***	-0.087	0.102***	0.103***	0.052*
	(0.052)	(0.039)	(0.069)	(0.029)	(0.019)	(0.028)
Local supply	0.022**	-0.002	-0.008	0.061	0.007	0.019
	(.011)	(.004)	(.006)	(.042)	(.004)	(0.011)
Regional income	-0.214***	0.087**	-0.079**	0.061**	0.018	-0.017
	(0.059)	(0.032)	(0.031)	(0.032)	(0.028)	(0.025)
Tariff	0.069***	-0.048	0.211	0.350***	0.018	0.186***
	(0.026)	(-0.034)	(0.117)	(0.065)	(0.014)	(0.073)
Tariff × Distance	-0.022	0.007	-0.041	-0.008	-0.063***	0.021
	(0.031)	(0.023)	(0.029)	(0.031)	(0.017)	(0.036)
$(\text{Tariff} \times \text{Distance})^2$	6.15e-06	3.20e-07	-5.41e-06	-3.11e-05	-7.31e-06	-2.52e-05
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Constant	6.69***	5.45***	5.22***	5.98***	5.38***	5.16***
	(1.24)	(0.85)	(0.71)	(0.81)	(0.51)	(0.55)

*, **, and ***; indicate the significant at 10%, 5%, and 1%, respectively. The amount in parentheses is a standard error. PPI is the Producer Price Index (PPI) of agricultural production

3.3. Estimation of price-wage elasticities

The homogeneity of the explanatory variables was first tested to assess the impact of tariffs on wages and estimate the price-wage elasticity. Hayashi's C-statistic (2000) was used to reject the null hypothesis of price exogeneity at a 1% probability. To control for endogeneity, Equation (11) was estimated using two lags of the price variables as instrumental variables. The estimation results are presented in Table 3 using two methods: OLS and instrumental variable (IV). The provinces were aggregated into five regions based on the general extent and neighborhoods, which reduced the number of regional dummy variables. The coefficients of the control variable were significant in urban and rural areas and were as expected. Wages increased with age and education, and in both rural and urban areas, male heads of households generally earned more than their female counterparts. The employment management variables of the economy sectors (services, agriculture, industry, transportation) differed slightly between urban and rural areas. Agriculture offered the lowest wages for both urban and rural areas, while transportation and industry provided the highest wages in urban regions. This is because there is little or no development of industry and services in rural areas, and transportation costs are high. It is not surprising that the transportation sector pays high wages.

As mentioned in Table 3, estimates of the impact of food prices on wages have shown a significant and positive relationship between food prices and wages in urban and rural areas. Consequently, these findings confirm the study's second hypothesis that changes in food tariffs affect wages. It is important to consider the potential implications of this relationship, such as the impact on income inequality and the ability of individuals to afford necessities. Policymakers may need to take this relationship into account when considering measures to address rising food prices or to ensure fair wages for all workers. Further research could also delve into the specific mechanisms driving this relationship and how it may vary across different regions and sectors of the economy. This is consistent with the findings of Nicita (2004; 2009), Cherkaoui et al. (2011), Kareem (2014), Rasool & Tarique

(2018), Anwar & Guha (2023), Dix-Carneiro & Traiberman (2023), and Vellinga & Tanaka (2024). Furthermore, it was observed that skilled workers had a more significant impact on price trends than unskilled workers. The effect of wages on price trends was significant in all five urban and rural areas and varied across regions. This contradicts Nicita's (2004; 2009) findings but aligns with Kareem's (2014) and Hassan & Kornher's (2022) results. Hassan & Kornher (2022) found that in the long run, the impact of food prices on changes in rural wages has decreased, while the impact of urban wages has increased in some regions.

Table 3- Estimating price-wages elasticity in urban and rural areas

Variables	***Urban***		***Rural***	
	Wage regression (OLS)	*Wage regression (IV)*	*Wage regression (OLS)*	*Wage regression (IV)*
Food price- skilled labor in region 1	0.322*** (0.009)	0.432*** (0.024)	0.354*** (0.008)	0.357*** (0.041)
Food price- skilled labor in region 2	0.324*** (0.008)	0.437*** (0.028)	0.321*** (0.007)	0.391*** (0.036)
Food price- skilled labor in region 3	0.365*** (0.009)	0.439*** (0.027)	0.271*** (0.011)	0.343*** (0.029)
Food price- skilled labor in region 4	0.322*** (0.012)	0.423*** (0.023)	0.248*** (0.011)	0.436*** (0.032)
Food price- skilled labor in region 5	0.347*** (0.012)	0.4332*** (0.029)	0.245*** (0.011)	0.383*** (0.033)
Food price-unskilled labor in region 1	0.321*** (0.009)	0.363*** (0.03)	0.201*** (0.011)	0.341*** (0.029)
Food price-unskilled labor in Region 2	0.289 *** (0.008)	0.375*** (0.028)	0.234*** (0.009)	0.345*** (0.029)
Food price- unskilled labor in Region 3	0.263*** (0.008)	0.354*** (0.028)	0.214*** (0.006)	0.354*** (0.027)
Food price- unskilled labor in Region 4	0.278*** (0.011)	0.375*** (0.029)	0.232*** (0.008)	0.326*** (0.028)
Food price- unskilled labor in Region 5	0.281 *** (0.008)	0.375*** (0.023)	0.199*** (0.006)	0.326*** (0.027)
Age	0.647*** (0.009)	0.631*** (0.014)	0.434*** (0.010)	0.421*** (0.017)
Years of education	0.152*** (0.004)	0.121*** (0.027)	0.123*** (0.004)	0.081*** (0.019)
Gender	0.017* (0.009)	0.027* (0.013)	0.298*** (0.011)	0.332*** (0.014)
Household head	0.205*** (0.005)	0.191*** (0.008)	0.097*** (0.008)	0.098*** (0.008)
Services	0.123*** (0.025)	0.123*** (0.026)	0.131*** (0.015)	0.121*** (0.017)
Manufacturing	0.123 *** (0.024)	0.118*** (0.027)	0.175*** (0.017)	0.161*** (0.019)
Transport	0.103*** (0.019)	0.096*** (0.022)	0.201*** (0.014)	0.211*** (0.012)
Constant	0.923*** (0.071)	0.492*** (0.172)	1.92*** (0.056)	1.42*** (0.013)
R^2	0.681	0. 76	0. 65	0. 51
Statistics C	22.14***		35.32***	
	Shea partial adjusted R^2			
Food price lag- skilled labor in region 1	0.078		0.059	
Food price lag- skilled labor in region 2	0.073		0.063	
Food price lag- skilled labor in region 3	0.071		0.060	
Food price lag- skilled labor in region 4	0.072		0.067	
Food price lag- skilled labor in region 5	0.076		0.062	
Food price lag- unskilled labor in Region 1	0.068		0.081	
Food price lag- unskilled labor in region 2	0.075		0.085	
Food price lag- unskilled labor in region 3	0.071		0.084	
Food price lag- unskilled labor in region 4	0.069		0.083	
Food price lag- unskilled labor in region 5	0.070		0.082	

*, **, and *** indicate the significance at 10%, 5%, and 1% respectively, and the amount in parentheses is a standard error.

3.4. Estimation of welfare effects of tariff changes

Table 4 provides the results of estimating tariff changes on household welfare in urban and rural areas. The second column represents the average percentage of total effect from a second-order Taylor series expansion approximation concerning price and expenditure elasticity, and the third column indicates the average percentage of total effect from a first-order Taylor series expansion approximation. These tables provide details of the welfare effects of tariff changes for each province. Additionally, Figure 3 displays a map of Iran that describes the boundaries of the areas with their respective capitals.

Table 4- Welfare Effects of food tariff changes in urban and rural areas

Province	*Welfare effect (second-order Taylor series expansion approximation)*		*Welfare effect (first-order Taylor series expansion)*		*Impact of tariff changes on labor income* $\sum_{s,u} \theta_h^{s,u} dw_r^{u,s}$		*Effect of tariff changes on agricultural income* $\sum_g \theta_{hg}^x dp_{gr}$		*Consumption Expenditure*							
									Price effects						*Income effects*	
									Effects of tariff changes on consumption expenditures $-\sum_g \theta_{hg}^c dp_{gr}$		*Price effect of consumption expenditures* $-\frac{1}{2}\sum_g \varepsilon_g \theta_{hg}^c dp_{gr}^2$		*Cross price effect on consumption expenditures* $-\frac{1}{2}\sum_g \sum_{k\neq g} 2\varepsilon_{gk} \theta_{hg}^c dp_{gr} dp_{kr}$		*Income effects* $-\sum_g \eta_{hg} \theta_{hg}^c dp_{gr}$	
	Urban	*Rural*	*Urban*	*Rural*	*Urban*	*Rural*	*Urban*	*Rural*	*Urban*	*Rural*	*Urban*	*Rural*	*Urban*	*Rural*	*Urban*	*Rural*
Region 1	**1.9**	**-1.1**	**1.6**	**-0.5**	**-0.1**	**0.2**	**-0.3**	**0.3**	**1.9**	**-0.9**	**0.1**	**0.0**	**0.0**	**0.0**	**1.6**	**-0.7**
Tehran	3.2	0.1	0.2	-0.2	-0.1	-0.4	-0.4	0.0	1.9	0.3	0.1	0.0	0.0	0.0	1.7	0.3
Qazvin	5.9	-1.6	1.5	-0.5	-0.2	0.5	0.0	0.4	3.2	-1.5	0.1	0.0	0.0	0.0	2.8	-1.1
Mazandaran	0.9	-1.3	1.8	-0.3	0.0	0.5	-0.7	0.5	0.9	-1.3	0.0	0.0	0.0	0.0	0.6	-1.0
Semnan	2.4	-1.3	1.2	-0.6	-0.1	0.2	-0.5	0.1	1.7	-0.9	0.1	0.0	0.0	0.0	1.2	-0.7
Golestan	3.6	-1.9	3.0	-0.7	-0.2	0.5	-0.1	0.4	2.1	-1.6	0.1	0.0	0.0	0.0	1.7	-1.2
Qom	3.1	-0.8	1.8	-0.4	0.0	0.0	0.0	0.1	1.8	-0.6	0.1	0.0	0.0	0.0	1.3	-0.4
Region 2	**2.6**	**-2.1**	**1.3**	**-0.8**	**0.0**	**0.5**	**-0.2**	**0.4**	**1.5**	**-1.7**	**0.1**	**0.1**	**0.0**	**0.0**	**1.2**	**-1.3**
Esfahan	1.9	-1.8	1.1	-0.5	0.3	0.7	-0.4	0.8	1.2	-1.9	0.1	0.1	0.0	0.0	0.8	-1.4
Fars	2.6	-2.3	1.3	-0.6	0.0	1.1	-0.4	0.6	1.6	-2.3	0.1	0.1	0.0	0.0	1.3	-1.8
Bushehr	5.0	-1.6	2.6	-0.7	-0.3	0.3	0.0	0.2	2.9	-1.2	0.1	0.0	0.0	0.0	2.3	-0.9
Chaharmahal and Bakhtiari	1.7	-2.0	1.0	-0.8	0.2	0.5	-0.2	0.4	1.1	-1.7	0.1	0.1	0.0	0.0.	0.6	-1.3
Hormozgan	2.1	-3.2	1.1	-1.7	0.1	0.3	-0.1	0.2	1.2	-2.2	0.0	0.1	0.0	0.0	1.0	-1.6
Kohgiloyeh and Boyerahmad	2.2	-1.4	1.0	-0.7	0.1	0.2	-0.3	0.1	1.3	-1.0	0.0	0.0	0.0	0.0	1.1	-0.7
Region 3	**2.6**	**-1.4**	**1.3**	**-0.5**	**0.0**	**0.5**	**-0.5**	**0.4**	**1.4**	**-1.3**	**0.1**	**0.0**	**0.0**	**0.0**	**1.3**	**-1.0**
East Azarbaijan	2.5	-0.9	1.4	-0.4	0.1	0.2	-0.2	0.1	1.4	-0.8	0.1	0.0	0.0	0.0	1.1	-0.5
West Azerbaijan	3.8	-1.5	2.1	-0.4	0.2	0.7	-0.4	0.3	2.4	-1.5	0.2	0.0	-0.1	0.0	1.6	-1.1
Ardabil	1.7	-1.8	0.7	-0.3	0.0	0.9	-0.6	0.7	1.2	-1.9	0.1	0.1	0.0	0.0	1.0	-1.5
Zanjan	2.2	-1.7	1.0	-0.7	0.0	0.2	-0.4	0.4	1.5	-1.3	0.1	0.0	0.0	0.0	1.1	-1.0
Gilan	4.3	-0.5	1.7	0.0	-0.3	0.2	-1.1	0.4	3.1	-0.6	0.2	0.0	-0.1	0.0	2.5	-0.5
Kurdistan	1.4	-2.3	0.7	-1.0	0.1	0.5	-0.4	0.4	1.1	-1.9	0.1	0.1	0.0	0.0	0.6	-1.4
Region 4	**0.9**	**-1.4**	**0.5**	**-0.5**	**0.2**	**0.5**	**-0.4**	**0.4**	**0.7**	**-1.3**	**0.1**	**0.0**	**0.0**	**0.0**	**0.3**	**-1.0**
Kermanshah	1.0	-1.2	0.7	-0.4	0.2	0.4	-0.3	0.3	0.8	-1.2	0.1	0.0	-0.1	0.0	0.2	-0.8
Ilam	0.7	-1.5	0.6	-0.3	0.7	0.8	-0.7	0.4	0.6	-1.5	0.1	0.0	0.0	0.0	0.0	-1.2
Lorestan	0.9	-2.0	0.3	-0.7	0.1	0.6	-0.7	0.5	0.9	-1.8	0.1	0.0	0.0	0.0	0.5	-1.4
Hamedan	1.3	-2.0	0.7	-0.8	0.1	0.4	-0.3	0.5	0.9	-1.7	0.1	0.0	0.0	0.0	0.6	-1.2
Markazi	0.0	-0.5	-0.1	-0.2	0.0	0.1	0.0	0.1	-0.1	-0.5	0.0	0.0	0.0	0.0	0.1	-0.3
Khuzestan	1.3	-1.4	0.8	-0.4	0.1	0.5	-0.2	0.3	0.9	-1.3	0.1	0.0	0.0	0.0	0.4	-1.0
Region 5	**1.4**	**-1.7**	**0.8**	**-0.7**	**0.1**	**0.4**	**-0.5**	**0.3**	**1.1**	**-1.4**	**0.1**	**0.0**	**0.0**	**0.0**	**0.6**	**-1.1**
Razavi Khorasan	2.7	-1.6	1.2	-0.5	-0.2	0.6	-0.3	0.4	1.7	-1.5	0.1	0.0	0.0	0.0	1.4	-1.1
South Khorasan	1.5	-1.3	0.6	-0.6	0.0	0.2	-0.9	0.2	1.4	-1.0	0.1	0.0	0.0	0.0	0.9	-0.7
North Khorasan	2.5	-1.2	1.2	-0.5	0.0	0.2	-0.7	0.2	1.8	-0.9	0.1	0.0	-0.1	0.0	1.2	-0.7
Kerman	0.6	-2.6	0.5	-1.1	0.2	0.4	-0.1	0.7	0.5	-2.2	0.1	0.1	0.0	0.0	0.1	-1.6
Yazd	0.7	-0.9	0.6	-0.1	0.5	0.6	-0.8	0.3	0.9	-1.0	0.1	0.0	-0.1	0.0	0.1	-0.8
Sistan and Baluchestan	0.5	-2.7	0.5	-1.3	0.3	0.5	-0.1	0.3	0.4	-2.1	0.1	0.1	0.0	0.0	0.0	-1.5
All urban and rural areas	**2.1**	**-1.6**	**1.1**	**-0.6**	**0.1**	**0.4**	**-0.4**	**0.3**	**1.4**	**-1.3**	**0.1**	**0.0**	**0.0**	**0.0**	**1.0**	**-1.0**

Figure 3- Iran's Political Map with the international boundaries, provinces boundaries, and their capital

Tariff changes in urban areas led to a rise in household welfare in nearly all provinces, except for *Markazi* province, which did not experience any welfare benefits from these changes. However, the distribution of these benefits varied across different provinces. In urban areas, the food tariff changes benefitted consumers across the country (by 2.5%) and were complemented by minimal wage income benefits (0.1%), which compensated for the losses incurred by producers (-0.4%) and contributed to an overall welfare increase of 1.2%. Furthermore, the provinces of *Qazvin, Bushehr, Gilan, West Azerbaijan, Golestan, Tehran, and Qom* benefited the most from the recent tariff changes. These changes increased these provinces' real incomes by 5.9%, 5.0%, 4.3%, 3.8%, 3.6%, 3.2%, and 3.1%, respectively. These findings confirm our third hypothesis that increasing food tariffs has a significant impact on the welfare of both urban and rural households. The confirmation of this hypothesis highlights the critical implications of food price increases on the overall welfare of households, both in urban and rural settings. This suggests that changes in food tariffs can directly affect the purchasing power and standard of living of individuals and families in these areas. It underscores the importance of understanding and addressing the impact of food price fluctuations on household welfare through targeted policies and interventions. These findings emphasize the need for strategies to mitigate the potentially negative effects of rising food prices on vulnerable populations and ensure equitable access to affordable and nutritious food for all. However, the provinces of *Lorestan, Mazandaran, Yazd, Ilam, Kerman, Sistan and Baluchestan*, and *Markazi* experienced the lowest benefits. This can be attributed to the fact that agricultural producers in these provinces tend to incur more losses than others. The other areas experienced an average level of profit. This result is in line with the findings of Ghosh et al. (2023), which showed that trade gains depend significantly on regional structural transformation.

Households in rural areas across the country have experienced a decrease in welfare by 1.6% due to changes in tariffs. Despite the benefits of agricultural income and wage gains, which increased by 0.7%, they were not enough to compensate for the losses suffered by consumers, which amounted to 2.3%. This means that rural households in the country have lost out due to changes in food tariffs. All provinces have been affected except for Tehran, which only experienced a 0.1% loss. The highest income reductions, exceeding 3%, were observed in the provinces of *Hormozgan*, and *Sistan and Baluchestan*, while the provinces of *Kerman, Kurdistan*, and *Fars* experienced income reductions of over 2%. Changes in the consumer channel mainly caused these losses. In most provinces of the country, including *Chaharmahal and Bakhtiari, Lorestan, Hamedan, Golestan, Isfahan, Ardabil, Zanjan, Razavi Khorasan, Qazvin, Bushehr, West Azarbaijan, Ilam, Kohgiluyeh and Boyer-Ahmad, Khuzestan, South Khorasan, Mazandaran, Semnan, Kermanshah, and North Khorasan*, losses between -2 and -1 percent were experienced. However, in other provinces, losses were less than one percent. This indicates that the impact of trade policies is not uniform across the regions. The results obtained from the first and second-order approximation of Taylor's expansion indicated that losses and benefits achieved in the first-order expansion were less than in the second-order approximation. The first-order approximation fails to account for the behavioral reactions to product substitutes, leading to biased results. The results align with the Wang et al. (2024) findings that trade liberalization in consumer goods has enhanced the consumption welfare of urban Chinese households across regions.

4. Conclusions

The results of this study shed light on the effects of food tariff changes on urban and rural households' welfare in Iran. The model used in this study is a comprehensive one that examines welfare effects at the microdata level. The finding indicates that tariff pass-through for prices of different food groups in urban and rural range from 9.1 to 19.1% and 4.8 to 35%, respectively. These findings indicate that firstly, in rural areas, prices increase due to weak or lack of tariff pass-through. Secondly, these levels of tariff pass-through are a little smaller than what is found in other countries, which depends on the conditions of Iran's economy and international trade policies. Consequently, the consumers do not benefit much from tariff changes. Meanwhile, increasing distances to borders and ports reduces the extent of tariff pass-through to prices. Provinces located near ports and customs benefit more in urban areas than those located farther away. Regions in the east, southeast, and central provinces, experience a reduction in welfare with increasing distance from major ports. The most significant losses in rural areas have been in the south and southeast regions of the country. This difference in results depends on multiple factors such as household characteristics, trade cost, consumption pattern, the structure of the local market, the way that trade policy transfers to prices, producers or consumers of agricultural products, the way that wages change, households' utilization of labor, and partly the difference between skilled and unskilled labor.

The findings on the welfare effects demonstrated that the tariff reduction had a net positive impact on the welfare of urban households, while it was detrimental to rural households. At the national level and in urban areas, the households' benefits from the reduced tariffs on food groups exceeded their losses, generally increasing the welfare of urban households. However, in rural areas, the benefits from rising agricultural income and wages could not compensate for the losses incurred by rural consumers, resulting in a decrease in the welfare of rural households. Consequently, the tariff reduction policy benefited urban residents, but negatively impacted rural households due to the limited tariff pass-through. In urban areas, the benefits are predominantly derived from the consumption of goods, while in rural areas, they are primarily generated through the income of labor and farmers. The weak or lack of tariff reductions pass-through to food prices in rural areas has led to a certain increase in prices. Consequently, consumers in these areas have suffered, but these changes have benefited producers and labor. Compared to rural areas, the impact of wages and producers' income in urban areas has been declining in most provinces. In other words, in rural areas, the reduction in tariff rates has been more advantageous for producers and labor, but detrimental to rural consumers. In urban areas, it has been more beneficial for consumers but detrimental to producers and labor. Hence the producers in urban areas have been more affected by the reduction in tariff rates. This is due to the higher pass-through of tariff reductions to prices in urban areas compared to rural areas, leading to a decrease in prices in these regions. Overall, the findings indicate that the tariff reduction has been beneficial for urban households but detrimental to rural households. This is related to higher tariff-pass through for food items which have a greater share in household expenditure. This leads to the transmission of border prices to urban households and the failure of tariff reduction pass-through to the prices of most food items in rural areas. It is important to note that the calculated welfare effects stem from multiple factors, including proximity to the port, local market structure, local supply and household demand behavior, and crucially, the ability of the local market to translate trade policy changes into domestic price changes. In other words, the efficiency of the market is a key determinant. Ultimately, the average household welfare is higher in urban areas of provinces that can more effectively pass on tariff reductions to consumers.

The findings indicate that the ability or lack of regional markets to achieve pass-through or international prices relative to domestic prices. Therefore, restructuring the local market is crucial before policymakers join the World Trade Organization. In other words, since the market cannot transfer the benefits of tariff changes to all households equally, the Iranian government must increase tariff pass-through to prices before joining the World Trade Organization and implementing worldwide trade liberalization. This can be done by improving infrastructure and reducing trade and transport costs, especially in rural areas, to benefit from trade liberalization. Moreover, losses of producers and vulnerable populations should be minimized by increasing productivity, promoting science and technology, subsidizing agricultural inputs, and increasing investment in the agriculture sector.

References

Anwar R & Guha A (2023). A study on dynamics of food inflation in India. *The Indian Economic Journal* 71(5): 783-804. https://doi.org/10.1177/00194662231186555

Bansah M & Mohsin M (2021). Welfare implications of trade liberalization when revenue matters. *The Journal of International Trade & Economic Development* 30(4): 574-595, https://doi.org/10.1080/09638199.2021.1883722

Campa J & Goldberg L (2002). Exchange rate pass-through into import prices: A macro or micro phenomenon, *NBER Working Paper*, No. 8934

Chao C C, Ee M S, Nguyen X & Yu E S E (2019). Trade liberalization, firm entry, and income inequality. *Review of International Economics* 27(4): 1021–1039. https://doi.org/10.1111/roie.12413

Cherkaoui M, Khellaf A & Nihou A (2011). The price effect of tariff liberalization in Morocco: Measuring the impact on household welfare. Working Paper, 637, *Economic Research Forum*.

Cho, S. W. & Diaz, J. P. (2010). The welfare impact of trade. *Economic Inquiry* 49(2): 379-397

Dhamija N (2023). Distributional Effects of Trade Liberalization on Wages in India. *Foreign Trade Review*, 0(0). https://doi.org/10.1177/00157325221126588

Dix-Carneiro R & Traiberman S h (2023). Globalization, trade imbalances and inequality. *Journal of Monetary Economics* 133(3): 48-72. https://doi.org/10.1016/j.jmoneco.2022.10.002

Echeverría L & Molina J A (2022). How does household welfare vary in response to changes in food prices? Poor vs. non-poor households. *Applied Economics Letters* 31(9): 854–862. https://doi.org/10.1080/13504851.2022.2153788

Ghosh S, Doğan B, Can M, Shah MI & Apergis N (2023). Does economic structure matter for income inequality? *Quality and Quantity*, 57: 2507–2527. https://doi.org/10.1007/s11135-022-01462-1

Han, J., Liu, R., Marchand, B. U. & Zhang, J. 2016. Market structure, imperfect tariff pass-through, and household welfare in Urban China. *Journal of International Economics* 100: 220-232. https://doi.org/10.1016/j.jinteco.2016.02.006.

Hassan F & Kornher L (2022). Farm wage and Rice Price dynamics in Bangladesh. *Food Security* 14: 127–146. https://doi.org/10.1007/s12571-021-01187-3

Hayashi F (2000). *Econometrics*. Princeton, NJ: Princeton University Press.

Hossain S M (2011). Liberalizing Agriculture by OECD Countries: Welfare, Growth and Distributional Impact in Developing Countries. *International Journal of Economics and Finance* 3(3): 167-176

Husted, S. & Melvin, M. (2012). *International Economics*. 9th Edition, Pearson, England.

Hyun-Jung N, Frijns B & Ryu D (2024). Trade openness and income inequality: The moderating role of institutional quality. *Global Finance Journal*, 60, 100959. https://doi.org/10.1016/j.gfj.2024.100959.

Kareem O I (2014). The welfare impact in Nigeria of the ECOWAS common external tariff: A distributional effects analysis. United Nations Conference On Trade and Development, *Trade Policies, Household Welfare and Poverty Alleviation*: *Case studies from the Virtual Institute academic network*, New York and Geneva

Khan M A, Walmsley T & Mukhopadhyay K (2021). Trade liberalization and income inequality: The case for Pakistan. *Journal of Asian Economics* 74(C): 101310

Le, M.S. (2014). Trade openness and household welfare within a country: A microeconomic analysis of Vietnamese households. *Journal of Asian Economics* 33: 56-70

Lopez A V, Cicatiello C, Principato L & Secondi L (2022). Consumer expenditure, elasticity and value of food waste: A Quadratic Almost Ideal Demand System for evaluating changes in Mexico during COVID-19. *Socio-Economic Planning Sciences* 82: 101065. https://doi.org/10.1016/j.seps.2021.101065

Marchand BU (2012). Tariff pass-through and the distributional effects of trade liberalization. *Journal of Development Economics* 99(2): 265-281

Marchand B U. (2019). Inequality and trade policy: the pro-poor bias of contemporary trade restrictions. *Review of Income and Wealth* 65: 123-152. https://doi.org/10.1111/roiw.12433

Mensah I (2019). Trade liberalization and its impact on income distribution in Ghana. *Transnational Corporations Review* 11(3): 208-221. https://doi.org/10.1080/19186444.2019.1642058

Mogendi J O, Nganga T K & Barasa L N (2023). Pass-Through Effects of the East African Community Common External Tariffs on Kenya's Domestic Prices. *Journal of Economic Integration 38*(3): 466–495. https://www.jstor.org/stable/27242697

Muñoz T M G, Baleix J M & Odeh O (2020). Inequality in Latin America: the role of the nature of trade and partners. *Economics*, 14 (1): 2020-25. https://doi.org/10.5018/economics-ejournal.ja.2020-25

Murakami Y (2021). Trade liberalization and wage inequality: Evidence from Chile. *The Journal of International Trade and Economic Development* 30(3): 407-438. https://doi.org/10.1080/09638199.2020.1871502.

Naanwaab C (2022). The Impact of Trade Liberalization on Income Inequality: Does the Direction of Trade Matter? *International Economic Journal* 36(6): 1-32. https://doi.org/10.1080/10168737.2022.2105378

Nicita A (2004). Who benefited from trade liberalization in Mexico? Measuring the effects on household welfare. *World Bank Policy Research, Working Paper*, 3265.

Nicita A (2009). The price effect of tariff liberalization: Measuring the impact on household welfare. *Journal of Development Economics* 89: 19–27

Okodua H (2014). Household Welfare Impact of Trade Liberalization in Nigeria: A Computable General Equilibrium Model. 17th Annual Conference on Global Economic Analysis, June 18 – 20, 2014, Dakar, Senegal.

Poi B (2012). Easy demand-system estimation with QUAIDS. *The Stata Journal* 12(3): 433-446.

Porto G (2006). Using survey data to assess the distributional effects of trade policy. *Journal of International Economics*, 70(1): 140–160.

Rasool H & Tarique M D (2018). Testing the link between Rural Wages and Food Inflation in India An Co-integration Approach. *Journal of Business and Management*, 20(1): 87-98. https://doi.org/10.9790/487X-2001018798

Rojas-Vallejos J & Turnovsky S J (2017). Tariff reduction and income inequality: Some empirical evidence. *Open Economies Review* 28(4): 603–631. https://doi.org/10.1007/s11079-017-9439-

Rosenfeld T, Mota I & Pereira E (2024). International Trade and Income Inequality: The Case of Latin American Countries. *The International Trade Journal* 38(4): 1–21. https://doi.org/10.1080/08853908.2024.2341624

Seshan G K (2014). The Impact of Trade Liberalization on Household Welfare in a Developing Country with Imperfect Labor Markets. *The Journal of Development Studies* 50(2): 226-243

Sethi, P., Bhattacharjee, S., Chakrabarti, D. & Tiwari, Ch. (2021). The impact of globalization and financial development on India's income inequality. *Journal of Policy Modeling* 43: 639–56

Shinyekwa, I.M.B., Bulime, E.N.W., & Nattabi, A.K. (2021). Trade, revenue, and welfare effects of the AfCFTA on the EAC: An application of WITS-SMART simulation model. *Business Strategy and Development* 4(1): 59–74. https://doi.org/10.1002/bsd2.157

Silva R P & Krivonos E (2021). The effects of trade openness on rural-urban sectoral employment, wages, and earnings: Evidence from Peru's second wave of trade liberalization. *The Journal of International Trade & Economic Development* 30(8): 1138-1167. https://doi.org/10.1080/09638199.2021.1936134

Tabash M I, Elsantil Y, Hamadi A & Drachal K (2024). Globalization and Income Inequality in Developing Economies: A Comprehensive Analysis. *Economies* 12(1): 1-23. https://doi.org/10.3390/economies12010023

Taylor J E, Naude, A Y & Jesurun-Clements N (2010). Does agricultural trade liberalization reduce rural welfare in less developed countries? The case of CAFTA. *Applied Economic Perspectives and Policy* 32(1): 95-116

The Islamic Republic of Iran Customs Administration. (2020). *Import and export regulations and annex tables for 2005-2020*. The commercial publishing company, Tehran, Iran

Topuz S, & Dağdemir O (2020). Analysis of the relationship between trade openness, structural change, and income inequality under Kuznets curve hypothesis: The case of Turkey. *The Journal of International Trade & Economic Development* 29(6): 647-664

Vellinga N & TanakaT (2024). Updating the analysis of rice import liberalization in Japan: a dynamic-stochastic CGE modelling approach. *Applied Economics*, pp. 1–19. https://doi.org/10.1080/00036846.2024.2305617

Vo T T & Nguyen D X (2021). Impact of Trade Liberalization on Household Welfare: An Analysis Using Household Exposure-to-Trade Indices. *Social Indicator Research*, 153: 503–531. https://doi.org/10.1007/s11205-020-02499-1

Wang B, Qian X, Li Y & Cao J (2024). Pro-poor consumption effects of trade liberalization: Evidence from China. *China Economic Review*, 86, 102189. https://doi.org/10.1016/j.chieco.2024.102189.

Appendix

Table A- The QUAIDS model estimates of food groups in urban and rural areas

	Cereal		*Meat*		*Dairy*		*Oils and Fats*		*Fruit, Veg., & pulses*		*Sugar*	
	Urban	***Rural***	***Urban***	***Rural***	***Urban***	***Rural***	***Urban***	***Rural***	***Urban***	***Rural***	***Urban***	***Rural***
α	-0.34***	-0.52	0.81***	0.23***	0.00	0.17***	0.07***	-0.02	0.34***	0.65***	0.10***	0.01
	(0.02)	(0.03)	(0.04)	(0.03)	(0.03)	(0.02)	(0.01)	(0.02)	(0.04)	(0.07)	(0.01)	(0.02)
β	-0.13***	-0.13***	0.13***	-0.02	-0.02***	0.08***	0.007*	-0.66***	0.00	0.20***	0.006*	-0.05***
	(0.00)	(0.02)	(0.01)	(0.03)	(0.00)	(0.01)	(0.00)	(0.01)	(0.00)	(0.02)	(0.00)	(0.01)
γ_1	0.15***	0.04***										
	(0.00)	(0.00)										
γ_2	-0.15***	0.00	0.15***	0.01								
	(0.01)	(0.00)	(0.01)	(0.00)								
γ_3	0.02***	-0.01***	0.00	0.02***	0.00	0.00						
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)						
γ_4	-0.008**	0.01***	0.008***	0.008*-	0.00	0.00	0.003**	0.03***				
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)				
γ_5	-0.01	-0.04***	0.01**-	-0.04***	0.00	0.00	-0.004**	-0.03***	0.02***	0.14***		
	(0.00)	(0.00)	(0.00)	(0.01)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.02)		
γ_6	-0.01***	0.00	0.00	0.009*	-0.01***	-0.02***	0.00	0.00	0.007**	-0.03***	0.01***	0.03***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	*	(0.00)	(0.00)	(0.00)
									(0.00)			
λ	-0.004***	0.00	0.004***	-0.007***	-0.0007***	0.006***	0.0002**	-0.005***	0.00	0.01***	0.0003***	-0.006***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)

coefficient of household characteristic in urban and rural area

	η_1		**η_2**		**η_3**		**η_4**		**η_5**		**η_6**	
	Urban	**Rural**	**Urban**	**Rural**	**Urban**	**Rural**	**Urban**	**Rural**	**Urban**	**Rural**	**Urban**	**Rural**
household head edu.	0.00	0.002***	0.00	-0.002***	0.0002**	0.00	0.00	0.0006***	-0.0003**	-0.0009**	0.00	0.0005**
	(0.00)	(0.00)	(0.00)	(0.00)	0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
size	0.00	0.00	0.00	0.00	-0.0003**	0.00	0.00	0.00	0.00	0.00	0.0002***	0.00
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
0-14 years old - male	0.00	0.00	0.00	0.00	-0.0002**	0.00	-0.0009***	0.00	0.0001*	0.00	0.00	-0.0002**
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
15-64 years old - male	0.00	0.00	0.00	-0.005*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
older than 65 years old - male	0.01***	0.01**-	-0.01***	0.00	0.002**	0.006*	0.00	0.005**	0.00	0.00	0.00	0.01***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
0-14 years old - female	-0.004***	-0.03***	0.002***	0.02***	0.001***	0.009**	0.00	-0.01***	0.00	0.02***	0.0006***	0.00
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
15-64 years old - female	-0.003***	0.00	0.004***	0.00	-0.001***	0.00	0.0004*	0.00	0.00	0.003*	0.00	0.00
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Region 1	-0.007***	-0.03***	0.01***	0.02***	-0.003***	-0.01***	0.00	0.008***	-0.003***	0.00	0.001***	0.01***
	(0.00)	(0.01)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Region 2	0.005***	-0.03***	-0.003**	0.02***	0.0008*	-0.01***	0.001***	0.01***	-0.003***	-0.01*	0.00	0.01***
	(0.00)	(0.01)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Region 3	-0.007***	0.00	0.01***	0.008*	-0.001**	-0.008***	0.0008**	0.005**	-0.003***	-0.01***	0.001***	0.006**
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.003)	(0.00)	(0.00)
Region 4	-0.009***	0.00	0.01***	0.00	0.00	0.00	0.00	0.00	-0.002**	0.006*-	0.0009**	0.00
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)

*, **, and *** indicate the significant at 10%, 5%, and 1%, respectively. The amount in parenthesis is a standard error.