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Research Article

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Assessment of Pesticide Selection and Application Behaviors of Sugar Beet Farmers in Konya Province

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HIGHLIGHTS

- Sugar beet farmers are mainly advised by pesticide dealers when choosing pesticides.
- Sugar beet farmers have acquired pesticides from agricultural chemical dealers.
- Farmers emphasized legality, cost-effectiveness, and efficacy when choosing pesticides.
- Sugar beet farmers need improved safety measures for pesticide use and disposal.

Abstract

This study is undertaken to determine the behaviors of sugar beet farmers regarding pesticide selection and applications in the Çumra, Altınekin, and Seydişehir districts of Konya province, where sugar beet production is concentrated in 2023. A total of 20 sugar beet farmers were randomly selected from each district through a random sampling method, and evaluations were made based on their responses to 16 face-to-face questions. The results were calculated as percentages and presented in tables. The behaviors of farmers regarding pesticide selection and application practices were assessed in two stages. It was found that sugar beet farmers often seek information from pesticide dealers when choosing and determining the dosage of agricultural chemicals, and they mainly obtain pesticides from agricultural chemical dealers. It was noted that they acquire the chemicals when they start growing the crop, do not spray regularly for pests and diseases as a preventive measure, and pay attention to the legality, cost-effectiveness, and effectiveness of the pesticides they purchase. Half of the sugar beet farmers reported conducting at least two pesticide applications during the season, and the majority stated that they perform pesticide applications in the morning and afternoon. Farmers acknowledged the importance of pesticide residues but emphasized that the effectiveness of the pesticide was more crucial. They also reported not adhering to the waiting periods between the last pesticide application and harvest. Regarding pesticide handling, application, and post-application practices, it was observed that farmers partially protected themselves. They tended to spray excess pesticide-contaminated water at the edge of the orchard or on vacant land and dispose of empty pesticide containers haphazardly on the edge of the field.

Keywords: Farmer; Konya; Pesticide; Sugar Beet, Survey Study

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1. Introduction

Sugar beet (*Beta vulgaris* var. *saccharifera* L.) is one of the significant plants used in sugar production worldwide. According to statistics, 25% of the world's sugar production is obtained from sugar beets. While sugar cane was known as the raw material for sugar until the late 18th century, German Marggraf's determination in 1747 that the substance giving sweetness to beets is the same as in sugar cane-initiated efforts to produce sugar from beets. Commercial sugar production from sugar beets was realized by Marggraf's student, Franz Carl Achard, in 1802 at the factory he established with the beets he bred (Cooke and Scott 1993). The region's climatic conditions and cultivation techniques play a crucial role in obtaining income from cultivating a product. Meeting the necessary conditions for sugar beet cultivation is essential for both yield and quality (Tortopoğlu 1994). Sugar beet is a biennial plant known botanically as *Beta vulgaris* var. *saccharifera*, utilizing its root in the first year for sugar production and its above-ground organs in the second year for seed production. In the first year, it forms roots and leaves, while in the second year, it produces flowers and seeds. Sugar beet (*Beta vulgaris* var. *saccharifera* L.) is composed of water and dry matter in terms of chemical structure. Depending on climate, growing conditions, and the planted beet variety, the root contains 20-26% dry matter, and the leaves contain 11-19% dry matter. The majority of this dry matter is sugar (Anonymous 1996).

Sugar beet production takes place in 52 countries worldwide, and Turkey holds a 9.1% share in this global production. This places Turkey as the fifth-largest farmer globally, following Russia, the United States, France, and Germany. Turkey's position in this sector is unique among countries that exclusively produce sugar from sugar beets, influenced by climatic conditions (FAO 2022). Sugar beet production holds a significant place in Turkey, and according to data on sugar beet production in 2022, a total area of 2 975 096 acres was utilized for sugar beet cultivation in the country. This extensive cultivation area indicates a total sugar beet production of 19 253 962 tons in the country. Based on this production quantity, the yield obtained is 6 472 kg/ha (TÜİK 2023). The leader in sugar beet production in our country is Konya province, with a production of 1 066 371 tons (TÜİK 2022).

Plant protection products and practices play a crucial role in reducing production losses caused by harmful agents in agricultural production areas. Therefore, indiscriminate and uninformed use of agricultural chemicals in these areas poses a threat to human and environmental health. For this reason, a survey study was conducted in the sugar beet production areas of Konya province, which has significant sugar beet production potential, to determine the plant protection issues of farmers and reveal their awareness levels in the application of plant protection products. The data obtained from this study will provide valuable information for future similar studies in these areas.

2. Materials and Methods

The answers to 15 questions, obtained through face-to-face interviews, were collected from a total of 60 sugar beet farmers in Konya province, specifically in the Çumra, Altınekin, and Seydişehir districts, with an equal number of participants from each district. The farmers were selected using the Simple Random Sampling Method. These responses were then evaluated based on the percentage rates, both individually for each district and as an overall average. The assessment focused on understanding the behaviors of sugar beet farmers concerning pesticide selection and application practices.

3. Results

The behaviors of sugar beet farmers in the Çumra, Altınekin, and Seydişehir districts of Konya province regarding pesticide selection and applications were determined through a random sampling method. Evaluations were made based on the responses to 16 face-to-face questions posed to 20 sugar beet farmers selected from each district. The results are presented in tables, calculated as percentages, and provided below.

Tablo 1. Pesticide Selection and Application Behaviors of Sugar Beet Farmers in Konya Province (%)

Time of Procuring Pesticides	**Altınekin**	**Çumra**	**Seydişehir**	**Average**
A	80	30	25	45
B	20	45	45	36,66
C	0	20	25	15
D	0	5	0	1,67
E	0	0	0	0
B+C	0	0	5	1,67
(A: When starting to cultivate the crop, B: When a disease appears in the crop, C: When I see neighbors spraying, D: According to the pesticide schedule, E: Other)				
Source of Procurement for Pesticides				
A	50	65	55	56,67
B	0	0	0	0
C	0	0	0	0
D	10	15	30	18,33
E	0	0	0	0
A+B	10	5	0	5
A+D	20	15	15	16,67
A+B+D	10	0	0	3,33
(A: Agricultural Pesticide Dealer, B: Agricultural Credit Cooperative, C: Chamber of Agriculture, D: Sugar Beet Cooperative, E: Other)				
Criteria They Consider in Pesticide Selection				
A	40	15	0	18,33
B	20	10	15	15
C	0	0	0	0
D	0	10	25	11,67
E	0	0	5	1,67
F	0	0	0	0
A+B	20	0	5	8,33
A+D	0	10	0	3,33
A+E	20	0	0	6,67
B+D	0	25	25	16,67
B+E	0	0	15	5
A+B+D	0	10	0	3,32
B+C+D	0	5	0	1,67
B+D+E	0	10	10	6,67
A+B+C+D	0	5	0	1,67
(A: Having a license for the product I will use, B: Being effective, C: Compatibility, D: Economic viability, E: Being a well-known pesticide (Advertisement), F: Other)				
Number of Pesticide Applications				
A	0	10	0	3,33
B	20	60	70	50
C	60	25	30	38,34
D	20	5	0	8,33
(A:1, B:2, C:3, D:Other)				
Decision-Making on Pesticide Application Timing				
A	60	30	35	41,67
B	0	10	0	3,33
C	0	0	0	0
D	20	35	55	36,67
A+D	20	25	10	18,33
(A: Morning, B: Noon, C: Irrespective of time, D: Other)				

Behavior in the Selection of Pesticide Dosage by Farmers				
A	20	50	35	35
B	80	25	45	50
C	0	5	0	1,67
D	0	5	5	3,33
E	0	0	0	0
A+B	0	15	10	8,33
B+C	0	0	5	1,67
(A: I apply according to the label, B: I adjust according to the dealer's recommendation, C: I apply a bit more than indicated on the label, D: According to my own experience, E: I follow what other farmers do)				
Opinions on Regular Pesticide Application				
A	10	20	0	10
B	80	30	30	46,67
C	10	50	70	43,33
(A:Yes, B:Sometimes, C:No)				

Sugar beet farmers were asked the question, "When do you procure the pesticide for diseases observed or likely to be observed in your field?" The responses are provided in Table 1. According to Table 1, 45% of the farmers indicated that they procure pesticides when they start cultivating the crop, while 36.66% stated that they obtain pesticides when a disease appears in the crop. When analyzed by districts, farmers in Altınekin reported procuring pesticides at an 80% rate when starting crop cultivation, while in Çumra and Seydişehir, 45% mentioned obtaining pesticides when a disease is detected in the crop. Karataş (2009). In a study conducted in the Manisa region, the question "When were pesticides obtained against diseases or pests?" Almost all the farmers (61.3%) provide the necessary pesticides when diseases or pests occur in the products they grow. In a study by Aydın (2019) with chickpea farmers in the Elbistan district of Kahramanmaraş province, when asked about the timing of obtaining pesticides against weeds, diseases, and pests, 25 farmers among those cultivating areas of 1-10, 11-25, and 26-100 decares stated 'when pests are observed,' and 22 farmers stated, 'when pests are observed' and 'when neighbors start spraying.

The question regarding where sugar beet farmers procure agricultural pesticides was asked, and their responses are provided in Table 1. According to the table, 56.67% of the farmers reported obtaining the pesticides from agricultural pesticide dealers, while 18.33% mentioned sourcing them from the sugar beet cooperative. The survey results conducted by Akbaba (2010) with citrus farmers in Adana province revealed that 88.9% of the farmers procure the pesticides they use from agricultural pesticide dealers, while 11.1% obtain them from agricultural credit cooperatives. Aydın (2019) found that, within the scope of their study, 63 farmers cultivating on 1-10, 11-25, and 26-100 acres obtained agricultural pesticides from "Agricultural pesticide dealers," 4 individuals from the "Agricultural Credit Cooperative," and 27 individuals from both "Agricultural pesticide dealers" and the "Agricultural Credit Cooperative. Akar (2018) reported that 92.1% of farmers in Antalya province procure agricultural pesticides from agricultural pesticide dealers. Similarly, Tanrıvermiş (2000) found that 81.25% of tomato farmers in the Central Sakarya Basin, and Cevizci et al. (2012) determined that 47.9% of farmers in Çanakkale obtain their pesticides from agricultural dealers.

The criteria that farmers consider when selecting pesticides were surveyed, and the responses are provided in Table 1. Of the respondents, 18.33% mentioned that they pay attention to the product being licensed for use, 15% consider its effectiveness, and 11.67% prioritize its cost-effectiveness. Upon reviewing Table 1, it is observed that the majority of farmers primarily focus on the pesticide being licensed for the product, being cost-effective, and being effective in their selection criteria. Akar (2017) determined that farmers in Antalya province prioritize the effectiveness (77.8%) of agricultural pesticides when making purchases. Other factors, such as the pesticide being well-known (10.8%), its cost-effectiveness (5.8%), and other factors (5.6%), were also noted as considerations during the pesticide procurement process (Çalışkan 2022). As a result of the study they conducted with carrot farmers in Konya province, when buying/choosing agricultural pesticides, they should choose a well-known pesticide (28.75%), be effective (25%), be licensed for the product to be used (21.25%) and be economical (15%) and miscibility (10%) (Kaplan and Ayaz 2023). In the province of Mardin, when cherry farmers choose (purchase) pesticides (fungicides, herbicides and insecticides) used against diseases and pests, 10% are based on whether they have been used before, 34% on the recommended active ingredient, 30% on the brand and 26% on the product. They stated that they chose it based on its cheapness.

Farmers were asked how many times they sprayed sugar beets during the season and their answers are given in table 1. 50% of the farmers stated that they sprayed the land twice, 38.34% sprayed the land three times, and 3.33% sprayed once. 8.33% of the farmers reported that they sprayed 1-3 times during the production season, depending on the disease and pest conditions, and that it varied according to season and year. Taylan (2020) determined the pesticide use schedule of hazelnut growers within the same production season; It was determined that 31.3% (120) used one drug, 29.8% (114) used two drugs, and 23% (88) used three drugs. It was observed that 11.7 (45) of them sprayed four times. It was observed that 61.1% of the farmers spray once or twice a year. Sevim et al. (2023), when looking at the pesticides and the total number of pesticides made by farmers on a product basis, determined that on average a farmer sprays 3.23 times for wheat, 4.16 times for cotton and 1.71 times for corn. Aydin (2015). While 50% of Konya bean farmers declared that they sprayed twice, 28.3% sprayed three times, and 11.7% sprayed once, 10% stated that the number of sprayings they applied varied depending on the disease.

The answers of sugar beet farmers to the question "When do you prefer to spray during the day?" are given in Table 1. According to Table 1, 41.67% of the farmers stated that they sprayed in the morning, 36.67% stated that they sprayed in the afternoon, and 18.33% stated that they sprayed in the afternoon and in the morning. Batur et al. (2023) determined that among hazelnut farmers, 50% apply pesticides in the morning, 18% in the morning or evening, and 10% in the afternoon or evening. Additionally, 10% of the farmers apply pesticides during the afternoon or evening. Yeşilayer et al. (2016) reported, in a study conducted in the Zile district of Tokat province, that sunflower farmers apply pesticides for pest control, disease management, and weed control. According to the findings, 87% of the farmers apply pesticides in the morning and afternoon, while 13% apply them at noon. Ediboğlu (2019) indicated, based on their study with tobacco farmers, that 57.7% prefer to perform pesticide applications in the morning, while 26.8% choose either the morning or the afternoon.

Table 1 provides the aspects that farmers consider when determining the dosage of pesticides. According to the table, 35% of the farmers determine the dosage based on the label, 50% determine it based on the dealer's recommendation, and 8.33% mentioned that they apply by determining the dosage both according to the label and the dealer's recommendation. Çevik (2019) found that 59% of pistachio farmers in the GAP Region determine pesticide dosage based on the recommendations of pesticide dealers, while 27% rely on experience or recommendations from other farmers. Similarly, Erdil (2019) reported that 63.8% of farmers in Manisa province determine the pesticide dosage based on the recommendations of pesticide dealers. Erdoğan et al. (2017) determined that almond farmers in Adıyaman province select pesticide dosage in chemical control as follows: 52.7% rely on pesticide dealers, 25.8% on the Agriculture Provincial Directorate, 17.2% on private consultants, 3.2% on their own experience, and 1.1% based on their neighbor's recommendation. Kalıpcı et al. (2011) reported that in Konya province, when determining the dosages of pesticides used by farmers, 8.3% adhere to the dosage written on the pesticide packaging label, 26.6% adjust the dosage based on trial and error and their own experiences, 11.6% adjust the dosage by adding a slightly higher amount than what other known farmers suggest, 33.3% follow the recommendations of pesticide dealers, 10.8% determine the application dosage by consulting the Agricultural Provincial and District Directorates, 3.3% consult Agricultural Chambers, and 5.8% consult Agricultural Engineers.

Table 1 presents the responses of farmers to the question 'Do you regularly spray pesticides at regular intervals for preventive purposes before encountering any disease or pest?' According to the results in Table

1, 46.67% of sugar beet farmers sometimes apply pesticides for preventive purposes, 43.33% do not spray pesticides for preventive purposes, and 10% indicated that they regularly spray pesticides for preventive purposes. According to another study conducted by Çalışkan (2022) in Konya province, carrot farmers have reported that 37.5% of them do not perform pesticide applications when diseases, pests, and weeds are not observed, 36.25% occasionally conduct pesticide applications, and 26.25% regularly engage in pesticide applications. According to Karaömerlioğlu (2019), 45% of farmers in the Gönen plain of Balıkesir province regularly spray pesticides at regular intervals without inspecting the plants, with the intention of avoiding encountering any diseases or pests. Additionally, 28% of the farmers sometimes engage in this practice, while 21% do not. 6% of the farmers did not provide a response to this question. Erdil (2019) reported that 64.3% of farmers in Manisa province do not engage in pesticide applications when diseases, pests, and weeds are not observed. Akar and Tiryaki (2017) stated that 54.5% of farmers in Antalya province do not perform pesticide applications when diseases, pests, and weeds are not observed.

Table 2. Pesticide Application and Post-Behavior of Sugar Beet Farmers in Konya Province (%)

Opinions on Residue Issue	**Altınekir**	**Çumra**	**Seydişehir**	**Average**
A	0	10	10	6,67
B	20	75	80	58,33
C	60	10	10	26,67
D	20	5	0	8,33
(A: What matters in spraying is eliminating the disease, B: Important, but the benefit of the pesticide is more important, C: Very important, more important than the benefit of the pesticide, D: I specifically consider the problems that residues can cause when spraying)				
Habit of Mixing Pesticides				
A	20	20	5	15
B	0	0	0	0
B-1	30	15	45	30
B-2	0	0	0	0
B-3	30	35	25	30
B-1+B-3	20	30	25	25
(A: No, B: Yes, B-1: To eliminate multiple diseases and pests in one spraying, B-2: To eliminate a single disease and pest by using multiple pesticides, B-3: To reduce the cost of spraying)				
Consciousness Level Regarding the Waiting Period for Pesticides				
A	20	60	60	46,67
B	50	5	0	18,33
C	15	30	15	20
D	15	5	25	15
E	0	0	0	0
(A: I harvest based on the maturity of the crop, B: I adhere to the necessary waiting period after spraying, C: I harvest based on market conditions, D: I don't pay attention to the waiting period, E: Other)				
Habit of Disposing of Excess Pesticide Waters				
A	70	30	20	40
B	15	35	65	38,34
C	0	0	0	0
D	0	10	0	3,33
E	15	10	15	13,33
A+B	0	15	0	5
(A: I pour it on one side of the garden, B: I spray it on vacant land, C: I discharge it into the irrigation channel or river, D: I pour it into the sewerage system, E: Other)				

Habit of Disposing of Empty Pesticide Containers				
A	30	65	75	56,67
B	0	5	0	1,67
C	0	25	15	13,33
D	70	5	10	28,33
E	0	0	0	0
(A: I throw it on the edge of the field, B: I throw it into the irrigation channel or river, C: I throw it into the general waste bin, D: I store it somewhere and then destroy it by burning, E: Other)				
Precautions Taken While Preparing Pesticides				
A	40	5	5	16,67
B	0	0	0	0
C	0	10	5	5
D	0	20	35	18,33
E	0	30	35	21,66
A+B	20	0	20	13,33
A+C	20	5	0	8,33
A+D	20	0	0	6,67
B+C	0	15	0	5
B+D	0	5	0	1,67
C+D	0	5	0	1,67
A+B+C+D	0	5	0	1,67
(A: I read the necessary information on the pesticide package, B: I use gloves and goggles when preparing pesticides, C: I pay attention to the thorough mixing of suspension and emulsion pesticides, D: I refrain from eating and drinking during pesticide preparation, E: I don't take any precautions.)				
Precautions Taken During Pesticide Spraying				
A	90	50	75	71,67
B	10	5	0	5
C	0	35	25	20
D	0	0	0	0
A+B	0	10	0	3,33
(A: I refrain from eating and drinking during pesticide spraying, B: I use protective clothing, C: I don't take any precautions, D: Other)				
Habits After Pesticide Application				
A	20	10	10	13,34
B	10	75	75	53,33
C	0	0	0	0
A+B	70	15	15	33,33
(A: I wash all my clothes after pesticide application, B: I wash thoroughly with water and soap, C: I do nothing.)				

The importance of residue issues due to chemical control was questioned to sugar beet farmers, and the results are provided in Table 2. According to this, 58.33% of the farmers stated that it is important, but the benefit of the pesticide is more significant. Meanwhile, 26.67% expressed that it is very important, with the residue being more significant than the benefit of the pesticide. Additionally, 6.67% emphasized the importance of eliminating the disease in pesticide application, while 8.33% mentioned that they particularly consider the problems that residues may cause when discarding the pesticide. Aydın and Boyraz (2015), in their study conducted in Konya, found that 45% of bean farmers consider the elimination of the disease more important than the residue issue in pesticide application. Meanwhile, 20% believe that the residue problem is significant, but the benefit of the pesticide is more crucial. Another 20% think that the importance of the residue problem surpasses the benefit of the pesticide, and 15% reported that they take into account the problems caused by residues when discarding the pesticide. In a study conducted by Kaplan and Ayaz (2023) in the Ömerli district of Mardin province, cherry farmers reported that 27% of them observed residues from agricultural pesticides in their products. Another 13% stated that this rate is low, and a majority of 60% mentioned that they did not observe any residues at all. Kalıpcı et al. (2011) reported that 45.8% of farmers believe that pesticide residues will be lost through rain and/or washing of the products. Additionally, 18.3% expressed the belief that there would be no pesticide residue in the products, while 28.3% acknowledged that residues could be present in the products. Furthermore, 7.5% stated that they had no knowledge about pesticide residues.

Sugar beet farmers were asked if they mix agricultural pesticides, and the reasons for mixing pesticides were inquired. According to Table 2, 15% of the farmers stated that they do not mix pesticides, while 85% reported that they use pesticides by mixing. Among those who mix pesticides, 30% stated that they mix them to eliminate multiple diseases and pests in a single spraying, 30% mix pesticides to reduce the cost of spraying, and 25% mix pesticides to both eliminate multiple diseases and pests and reduce costs in spraying. İnan (2001) in a study conducted in the Konya region, reported that 71.5% of the farmers use multiple pesticides by mixing them in chemical control, while 28.5% use pesticides without mixing them. Ulusay (2018) stated that 23.3% of tomato farmers in Aydın province mostly and 47.6% sometimes mix multiple pesticides. Peker (2012) found that 56% of tomato farmers use pesticides in a mixed form, 24% apply pesticides without mixing, and 20% occasionally mix pesticides. On the other hand, Erdoğan et al. (2017) reported that 78.5% of almond farmers apply agricultural pesticides by mixing them, 19.4% occasionally mix pesticides, and 2.1% apply individual pesticides without any mixing.

Farmers were surveyed regarding their attention to the waiting period after applying pesticides until the harvest time, and the results are presented in Table 2. The results indicate that 18.33% of the farmers pay attention to the waiting period, while 81.67% do not consider the waiting period. Among the farmers who do not pay attention to the waiting period, 46.67% harvest based on the ripening of the crop, 20% harvest based on market conditions, and 15% stated that they never consider the waiting period before harvesting. Özşahin (2021) reported that 91.03% of fruit farmers in Lapseki (Çanakkale) district do not adhere to the waiting period when harvesting their crops. Emeli (2006) conducted a survey in 2005 in the Seyhan and Yüreğir Basins with the aim of identifying the problems encountered in the implementation of plant protection methods. The study involved 50 agricultural pesticide dealers, 112 farmers, and 48 technical personnel. The findings indicated that they harvest their crops without adhering to the necessary waiting period after pesticide application. Kaplan and Ayaz (2023) reported that among the pesticide-using farmers in Ömerli, Mardin, 53.58% stated that they adhere to the waiting period between pesticide application and harvest, 32.14% mentioned that they do not adhere to it, and 14.28% indicated that they sometimes adhere to it.

The sugar beet farmers were asked where they discharge the excess pesticide-laden water after spraying, and the results are provided in Table 2. Farmers stated that 40% of the excess pesticide-laden water is poured along the edge of the garden, 38.32% is sprayed onto vacant land, 3.33% is poured into the sewage system, 13.33% is sprayed onto the road by opening the machine, and 5% is poured along the edge of the garden and sprayed onto vacant land. Çalışkan (2022) reported that in their research conducted in Konya and Ankara, 60% of the farmers mentioned that they dispose of the excess agricultural chemicals after usage and the water containing pesticides generated during the cleaning of the spraying tank by pouring it to the edge of the field. Additionally, 38.75% stated that they spray it onto vacant land. Karaömerlioğlu (2019) stated that 33% of the farmers in the Gönen Plain of Balıkesir province dispose of the excess agricultural chemicals after usage, as well as the water containing pesticides generated during the cleaning of the spraying tank, onto vacant land. Furthermore, 31% pour it into the sewage system, and 26% discharge it along the edge of the garden. Akbaba (2010) indicated that 67.3% of citrus farmers in Adana province stated that they dispose of the more medicated water on the edge of their orchards or on vacant land, while 13% mentioned pouring them into water channels, rivers, or sewage systems.

The disposal methods of empty pesticide containers after spraying were inquired from the farmers, and their responses are provided in Table 2. According to Table 2, 56.67% of sugar beet farmers dispose of empty pesticide containers by throwing them on the edge of the field, 28.33% store them somewhere and later burn them for disposal, 13.33% throw them into general waste bins, and 1.67% reported discarding them into irrigation channels or rivers. Tücer et al. (2004) reported that 60.54% of grape growers in Manisa province randomly discard empty pesticide containers, 4.98% repurpose pesticide boxes for different purposes, 19% bury them in the soil, and 15.48% dispose of them by burning. Gözener et al. (2017) found that 59.72% of tomato farmers in Tokat province dispose of used pesticide containers by burning them, 29.17% bury them underground, 5.56% place them in garbage areas with household waste, and 5.56% randomly leave them in their surroundings. Zeren and Kumbur (1998) revealed in their study conducted in İçel province that 45.29% of farmers randomly discard empty pesticide containers, 38.48% burn them, and 6.23% bury them in the soil after spraying.

Farmers were asked about the precautions they take while preparing pesticides, and their responses are provided in Table 2. According to this, it has been determined that 78.34% of the farmers take measures to protect themselves during pesticide preparation, even through different methods. Farmers have indicated that 16.67% read the necessary information on medication packaging, 5% ensure proper mixing of suspension and emulsion drugs, 18.33% refrain from eating and drinking during pesticide preparation, 13.33% read the necessary information on medication packaging and use gloves and goggles during preparation, 8.33% read the necessary information on packaging and ensure the proper mixing of suspension and emulsion drugs, and 5% mentioned using gloves and goggles during medication preparation while also paying attention to the thorough mixing of suspension and emulsion drugs. 21.66% of the farmers have stated that they take no precautions during the preparation of medications. In the Altınekin district, 40% of farmers have been observed to read the information on packaging. In contrast, in other districts, this rate is observed to be 5%. Altınekin district shows a higher level of awareness among farmers regarding the precautions taken in the preparation of medications. Aydoğan and Baran (2023) determined that 69.0% of tobacco farmers in the research area do not read the labels of the agricultural chemicals they use. Çalışkan (2022) reported that 40% of farmers do not use gloves when preparing agricultural chemicals, 32.5% use gloves, and 27.5% use them occasionally. In the Beypazarı district, the majority of farmers (52.5%) stated that they do not use gloves while preparing chemicals. In the Meram district, 30% of farmers use gloves, while 42.5% use them occasionally. Denkçi (2019) conducted a study on sunflower farmers in Edirne, asking about their self-protection measures during the preparation of pesticides. Out of 166 participants, 155 stated that they protect themselves, while 11 reported not taking protective measures.

The precautions taken by farmers during pesticide application were inquired, and their responses are provided in Table 2. According to these results, 71.67% of the farmers stated that they did not engage in eating or drinking during pesticide application, 20% did not take any precautions, 5% used protective clothing, and 3.33% mentioned that they refrained from eating or drinking during pesticide application and used protective clothing. Akar (2017), Erdil (2019), and Uzun (2021) reported that 84.1% of farmers in Antalya province, 68.5% of farmers in Manisa province, and 87% of hazelnut farmers in Kocaeli province stated that they did not smoke during pesticide application. Akar (2017) and Erdil (2019) reported that 87.8% of farmers in Antalya province and 92.4% of farmers in Manisa province indicated that they did not eat or drink anything during pesticide application. Aydın (2015) reported that 46.7% of bean farmers in Konya pay attention to not eating and smoking while applying pesticides, 30% did not take any precautions during pesticide application, 16.7% used protective clothing during pesticide application and 6.6% used protective clothing during pesticide application while also refraining from eating anything.

The sugar beet farmers were asked about the precautions they took after applying the pesticide, and their responses are provided in Table 2. According to the responses of the farmers, 53.33% mentioned that they carefully washed themselves with water and soap after pesticide application, 33.33% stated that they washed all their clothes, and 13.34% indicated that they washed themselves carefully with water and soap, also washing the clothes worn during pesticide application. According to the study conducted by Çalışkan (2022) with carrot farmers in Konya, 46.25% of the farmers stated that they changed their clothes after pesticide application, while 36.25% indicated that they occasionally changed their clothes. In the Meram district, 60% of farmers, and in the Beypazarı district, 32.5% of farmers reported changing their clothes after pesticide application. Regarding taking a bath after pesticide application, 48.75% of farmers mentioned doing so, and 37.5% indicated doing it occasionally. In response to this question, 62.5% of farmers in the Meram district answered 'yes,' 27.5% answered 'sometimes,' while in the Beypazarı district, 35% answered 'yes,' and 47.5% answered 'sometimes. According to the study conducted by Denkçi (2019) in Edirne province, when participants were questioned about their immediate actions after pesticide application, 102 out of 165 individuals (61.8%) reported performing handwashing, changing clothes, and taking a shower together.

Farmers were asked whether they received training on applying plant protection products, and 18.33% of the farmers reported receiving training on the application of plant protection products, while 81.67% stated that they did not receive training on the application of plant protection products. Batur et al. (2023) reported that, regarding the education levels on pesticides among farmers in Düzce province, the majority of farmers (71%) did not receive any training on pesticides, while 29% reported having received training. In the study conducted by Karaömerlioğlu (2019) with farmers in the Gönen Plain of Balıkesir province, it was observed that 18% had received training courses for the purpose of applying plant protection products, while 82% had not taken any training courses. Aydın and Sağlam (2019) determined that only 8.5% of chickpea farmers in the Elbistan district of Kahramanmaraş province received training on pesticide application.

4. Discussion

Sugar beet farmers, with 56.67%, primarily obtain their agricultural pesticides from dealers, and 50% of them determine the pesticide dosage by consulting with these dealers. In this case, individuals managing agricultural pesticide dealerships and those engaging with farmers must be specifically agricultural engineers. Additionally, 45% of farmers reported obtaining pesticides when they start growing the crop. It is essential for the agricultural engineer dealing with the farmer to have sufficient knowledge about potential diseases, pests, and weed damage in that region. This ensures that issues such as incorrect pesticide usage and excessive pesticide dosage are avoided.

It has been determined that a significant majority of sugar beet farmers, 85%, use agricultural pesticides by mixing them. Farmers argue that they mix pesticides to reduce costs and eliminate multiple diseases and pests. It has been observed that farmers choose this method to simplify their work and economically reduce expenses, but they may not be aware that the active substances of the mixed pesticides can interact, leading to serious problems for themselves and the development of resistance in pests or diseases. To prevent these issues, farmers should be carefully informed about the drawbacks of mixing pesticides. Much of this information dissemination responsibility falls on agricultural pesticide dealers because a significant portion of farmers source their pesticides from these dealers and direct their questions to the agricultural engineers working at these dealerships. Therefore, agricultural engineers working at pesticide dealerships should be trained by relevant departments of the Ministry of Agriculture and Forestry to provide information about which pesticides can be mixed and potential issues that may arise from mixing. This way, farmers can access this information more quickly and effectively.

A considerable portion of sugar beet farmers, 40%, stated that they spray the excess pesticide water on the edge of the garden, while 38.34% spray it on vacant land. It has been determined that a significant portion of farmers mix the excess pesticide water with the soil. Due to this behavior, the soil is heavily contaminated with pesticide residues. As a result, beneficial organisms in the soil are harmed, and ecological imbalances occur. Additionally, pesticide residues reduce germination in seeds planted in the next season, causing growth retardation or death in plants. To prevent farmers from haphazardly disposing of excess pesticide water, special areas should be designated in the production areas to ensure that the pesticide water does not mix with the soil.

More than half of the sugar beet farmers, specifically 56.67%, have been found to dispose of empty pesticide containers on the edge of the field. This habit of farmers not only pollutes the environment but also harms animals. Empty pesticide containers should be washed, punctured, and taken to collection areas. To instill this habit in farmers, collection areas should be established near production fields. Additionally, a deposit system should be implemented for empty pesticide containers to encourage farmers to participate in this practice. This way, farmers will have an incentive to adopt the practice, and environmental pollution and harm to animals will be reduced.

A significant portion of sugar beet farmers, 43.33%, stated that they do not regularly apply pesticides, while 46.67% mentioned that they occasionally do. Looking at the results, a significant portion of farmers do not seem inclined towards regular pesticide application. It is crucial to provide information to farmers about the benefits of regular pesticide application, emphasizing its potential to prevent a considerable portion of future diseases and increase yield by reducing plant stress. When farmers are informed about these aspects, excessive pesticide use can be avoided, leading to a decrease in pesticide costs, and the issue of pesticide residues in the soil can be substantially mitigated.

It was found that a large majority of sugar beet farmers, 81.67%, do not adhere to the recommended waiting period after pesticide application. It is crucial to communicate the significance of adhering to the waiting period to the farmers. To achieve this, institutions capable of conveying this important information should be established at the provincial, district, and village levels. If such an approach is followed, potential threats to human and animal health will be eliminated, and the issue of pesticide residues in exports can be mitigated.

The majority of sugar beet farmers, 78.34%, stated that they take certain precautions when preparing agricultural pesticides, while 21.66% mentioned that they do not take any precautions during spraying. However, the precautions taken may not provide complete protection. It should be emphasized to farmers that using a mask, gloves, and protective clothing is essential when preparing chemicals, and similarly, wearing a mask, gloves, and protective clothing is mandatory during pesticide application. The responsibility for conveying this information lies with the Agricultural Provincial/District Directorates. Meetings and training sessions should be organized for farmers at the beginning of the production season, providing them with masks, gloves, and protective clothing to instill the habit of using these products.

More than half of the farmers, 58.33%, have argued that the residue problem is important, but the benefit of the pesticide is even more crucial. When considering these results, it is evident that farmers are aware of polluting the environment with pesticides. However, this awareness is not deemed significant by the farmers. Consequently, this leads to a substantial accumulation of residues in the soil, causing harm to the surrounding organisms. It is necessary to overcome the farmers' lack of concern for the residue problem despite their awareness. Therefore, providing education to farmers on residue issues and environmental pollution is essential. These educational programs should draw attention to the potential harms of unconscious pesticide use and promote sustainable farming practices. Farmers should be guided on proper pesticide use, paying attention to dosages, and evaluating alternative solutions, encouraging them to adopt environmentally friendly agricultural practices. This way, it is possible to prevent residue problems and enhance environmental sustainability.

5. Conclusions

In conclusion, significant deficiencies are observed in farmers' use of agricultural pesticides. To address and resolve these issues and cultivate informed farmers. It is crucial to ensure that university students are thoroughly trained. Moreover, a substantial responsibility lies with the Ministry of Agriculture and Forestry, along with its affiliated Agricultural Provincial/District Directorates, to fulfill tasks related to training and promoting awareness among farmers.

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Assessment of Some Physical Properties and Germination Characteristics of Ereğli and Kırıkhan Local Population Black Carrot Seeds

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HIGHLIGHTS

- It is necessary to determine the physical properties of black carrot seeds from local populations in Ereğli and Kırıkhan.
- The germination behaviour of the seeds needs to be determined, and their differences highlighted.
- Such information will provide insights that can guide future studies in black carrot farming and seed processing technology.

Abstract

Nowadays, food production and food security are an extremely important issue. Seed is of great importance for maintaining and securing crop production capacity. It is also necessary to protect gene resources and to apply new technologies. This study examined physical properties and germination parameters of calibrated black carrot seeds from the local populations S_1 (Ereğli) and S_2 (Kırıkhan). The length, width, thickness, geometric mean diameter, sphericity, projected area, volume, thousand grain weight, bulk density and terminal velocity values of the seeds of S_1 population at 3.96% moisture content were determined as 3.95 mm, 1.65 mm, 0.98 mm, 1.84 mm, 0.47, 5.18 mm^2, 2.01 mm^3, 2.51 g, 0.431 gcm^{-3}, and 1.80 ms^{-1}, respectively. Moreover, those values for S_2 population seeds were found to be 3.61 mm, 1.46 mm, 0.82 mm, 1.62 mm, 0.45, 4.55 mm^2, 1.37 mm^3, 2.21 g, 0.395 gcm^{-3}, and 1.75 ms^{-1} at 4.45% moisture level, respectively. Final germination seed (FGS), mean germination time (MGT), germination index (GI), germination rate index (GRI) and coefficient of velocity of germination (CVG) values of S_1 and S_2 variety seeds were 85% and 81%, 4.52 and 3.50 days, 548.5 and 574, 20.85 and 28.52 % day^{-1}, 22.20 and 28.79, respectively. The data obtained from this study will guide future studies on black carrot cultivation and seed processing technology.

Keywords: Black carrot seeds; Physical properties; Germination parameters; Color characteristics

1. Introduction

In contemporary times, feeding the world's population is among the most significant challenges. For this reason, it is necessary to develop a large number of varieties due to the decrease in agricultural land, changing consumer preferences and the wide range of consumption of people.

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Carrot is one of the vegetable varieties known for many years and produced in our country. Carrot (*Daucus carota* L.), a member of the genus Daucus, is a cultivated plant of the Apiaceae family (Simon and Goldman 2007). Additionally, the black carrot species belongs to Daucus carota ssp. sativus var. atrorubens Alef. Black carrot originates from Turkey, the Middle and Far East as well as it has been cultivated for at least 3 000 years (Montilla et al. 2011).

Carrot is a root vegetable that contains many bioactive compounds, for example, carotenoids, phenolic acids and anthocyanins. In addition, carrots are great sources of vitamins as well as minerals. Due to bioactive compounds, a carrot provides significant health benefits. It was demonstrated that carrots display powerful antioxidant and radical scavenging activities. Moreover, the consumption of carrots has been linked with a lower risk of diseases such as atherosclerosis, cataract, diabetes and cancer (Sharma et al. 2012).

Black carrots exhibit a purple hue due to their abundant anthocyanin content. These anthocyanins demonstrate considerable stability when exposed to light, heat, and variations in pH, rendering them ideal for use as natural colorants in food products.

Black carrot extracts are currently employed as natural colorants across various industries, including food, textiles, cosmetics, and pharmaceuticals, as a replacement for synthetic dyes. Additionally, these extracts are utilized in the coloring of fruit juices, jellies, confectioneries, jams, canned and frozen desserts, ice creams, soft drinks, and other fermented beverages (Barczak 2005; Ersus and Yurdagel 2007). Approximately 20% of the black carrot yield is dedicated to the turnip industry, while the remaining 80% is used for concentrate production. There is no specific data regarding the production area and amount of black carrot according to TurkStat. However, carrot production area and amount were stated 77 660 da and 522 410 t for Konya, 22 022 da and 70 710 t for Hatay provinces as well as those values were 136 627 da and 777 908 t for Turkey in 2023, respectively (TurkStat 2024).

Black carrots are also produced in Ereğli and Karapınar Districts of Konya and Kırıkhan District of Hatay Province. In these regions, hybrid black carrot seeds as well as local population black carrot seeds are used. Geographical indication registration was obtained for both Ereğli population black carrot (Anonymous 2017) and Kırıkhan local population black carrot (Anonymous 2022a).

Seed is of strategic importance for the agricultural sectors of countries. Local population seeds are used in regions where black carrot is produced. These seeds should be certified. These seeds should not only be used as an agricultural input. Additionally, their economic value should be enhanced by using technology.

In Ereğli and Kırıkhan Districts, planting is implemented with local population black carrot seeds. The color value of the Kırıkhan local variety of black carrot surpasses that of the Ereğli variety. Therefore, concentrate companies prefer the cultivation of the Kırıkhan local population black carrot in Konya's Ereğli and Karapınar districts for its superior color quality in concentrates. Besides, seed production for both populations is also carried out in the Konya region.

Carrot seeds are small and usually yellowish to dark gray in color and often appear slightly fuzzy. These fuzzy make up approximately 20-30% of the seed weight.

Research on carrot seed production in our country is limited; however, there are some significant studies. Kiracı (2013), established the gene pool of various purple carrot types grown and used in industry in Konya and its surroundings, facilitating the selection of lines in the pool.

Lökoğlu (2019), investigated the effect of root size and storage conditions on seed yield and quality in seed carrot roots in the first stage and the effect of planting spacing on seed yield and quality characteristics in seed carrot roots in the second stage in order to solve the problem of seed production in black carrots.

Several studies have examined the physical properties of various seed varieties. Notable research includes investigations on sage seeds (Bayram et al. 2016), balm seeds (Dumanoğlu and Çakmak 2017), onion seeds (Dumanoğlu and Çakmak 2019), lettuce seeds (Çekim and Özarslan 2020), anise seeds (Dumanoğlu et al. 2020) and basil seeds (Dumanoğlu and Mokhtarzadeh 2021). However, there is a notable lack of studies on the physical and germination characteristics of calibrated bare black carrot seeds from the Ereğli and Kırıkhan local population black carrot seeds.

2. Materials and Methods

The production of two local population of black carrot seeds used in the research was carried out under by local farmers in the Ereğli region in 2023. Calibrated black carrot seeds were initially passed through rectangular sieves ranging from 1.75 to 1.50 mm, and then classified according to their specific gravity (Fig. 1).

Bare seeds Ereğli (S_1)

Bare seeds Kırıkhan (S_2)

Figure 1. Local population black carrot seeds used in the trials

Three groups of 50 seeds each were consisted of the Ereğli and Kırıkhan seeds separately and 50 seeds were randomly selected from both seed varieties. The dimensional properties and projected area of the bare black carrot's seeds were measured using the "Image Tool version 3.0" image processing software. Using the length and width values obtained from the seeds, geometric and shape characteristics were determined (Table 1).

Table 1. Classification of seeds according to their geometric and shape characteristics (Yağcıoğlu, 2015)

Classes of geometric characteristic	**Seed width/Seed length (W/L)**
Long	< 0.6
Medium	0.6-.07
Short	> 0.7
Classes of shape characteristics	**Length(L), width(W), thickness (T) (mm)**
Round	L ≈ W ≈ T
Oval	L/3 < W ≈ T
Long	T< W < L/3

The geometric mean diameter, sphericity, and volume of the bare seeds were calculated using specific equations (Mohsenin, 1970).

Table 2. Geometric mean diameter, sphericity and volume symbols and formulas

Parameters	**Units**	**Symbols**	**Equations**
Geometric mean diameter	mm	Dg	$(L.W.T)^{1/3}$
Sphericity	-	Ø	$\frac{D_g}{L}$
Volume	mm³	V	$\frac{\pi B^2 L^2}{6.(2L-B)}$
			$B=(WT)^{0.5}$

*L: Length of seeds, *W: Width of seeds, *T: Thickness of seeds

In three replicates, the mass of one thousand randomly selected seeds was determined by counting them using a Contador brand seed counting device and measuring their weight on a precision scale.

Bulk density was evaluated using a weight per hectoliter tester, which was calibrated to measure in kilograms per hectoliter (Deshpande et al. 1993). Seeds were extracted using a strike-off stick, and no compaction was applied during testing.

The color values of the black carrot seeds were measured using a Minolta Chroma Meter model CR 400 (Konica Minolta, Inc., Osaka, Japan) color measurement device. In the measurements, the L*, a*, and b* scales, as defined by the International Commission on Illumination, were used (Rizzo et al. 2014). The measurements were taken on the exterior (skin) part of the seeds In the CIE L*, a*, b* color system, the L* value represents lightness, ranging from 0 (black) to 100 (white). The a* value signifies the red-green axis, with positive values indicating redness and negative values indicating greenness. The b* value corresponds to the yellow-blue axis, with positive values indicating yellowness and negative values indicating blueness (Jha et al., 2006).

The coefficient of static friction of black carrot seeds was determined by measuring their interaction with sheet iron, plastic, and galvanized sheet iron surfaces. In this setup, one end of the friction surface was fixed to an endless screw. The black carrot seeds were positioned on the surface, and the screw was gradually lifted. When the seeds began to slide, the vertical and horizontal height values were recorded. The coefficient of static friction was subsequently determined by calculating the tangent of the angle at which the sliding initiated (Baryeh 2001).

The terminal velocities of black carrot seeds were determined using an air column. During each test, a seed was released into the air stream from the top of the column, where upward-blown, air was used to suspend it. The velocity of the air at the point of suspension was measured with an electronic anemometer, accurate to 0.1 m s^{-1} (Hauhouot-O'Hara et al. 2000; Joshi et al. 1993).

A Nüve FN055 brand owen was used to measure the moisture content of the black carrot samples. The samples were dried at 105°C until they reached a constant weight.

The germination tests of black carrot seeds were carried out in a climate chamber, adhering to ISTA 2023 norms (Anonymous 2023). A hundred seeds from two different black carrot populations were placed in petri dishes with four replicates each, and daily counts were conducted.

Some concepts related to germination characteristics of black carrot seeds were given in list in Table 3. These parameters pertain to the number of germinating seeds and the initial development of seedlings.

Table 3. Basic concepts of germination characteristics

Parameters	Units	Symbols	Equations	References
Final germination seed	%	FGS	100* (Number of germination seeds / Total number of seeds)	(Scott et al., 1984)
Mean germination time*	Day	MGT	$\frac{\Sigma N_i . T_i}{\Sigma N_i}$	(Orchard, 1977)
Germination index**	-	GI	$14xN_1+13.N_2+.....+1.N_{14}$	(Benech Arnold et al., 1991; Kader, 2005)
Germination rate index***	(% day^{-1})	GRI	$\frac{G_1}{1}+\frac{G_2}{2}+\frac{G_3}{3}+....+\frac{G_x}{14}$	(Al-Ansari and Ksiksi, 2016)
Coefficient of velocity of germination	-	CVG	$100 \cdot \frac{\sum N_i}{\Sigma N_i \cdot T_i}$	(Jones and Sanders, 1987)

*N_i is the number of germinated seeds for each day, T_i is number of days counted from the beginning of germination
**N_1, N_2 ...N_{14} is the number of germinated seeds on the first, second and subsequent days until 14th day and the multipliers (e.g. 14, 13, 12 ...etc.) weights are given to the days of the germination.
***G_1 is the germination percentage on day 1, G_2 is the germination percentage at day 2 and etc.

Variance analyzes were performed on the germination parameters of black carrot seeds using the MINITAB 16 program.

3. Results and discussion

3.1. Physical properties of black carrot seeds

Some physical properties of classified bare black carrot seeds from S_1 (Ereğli) and S_2 (Kırıkhan) local populations are detailed in Table 4. For S_1 seeds with a moisture content of 3.96%, the values are: length 3.95 mm, width 1.65 mm, thickness 0.98 mm, geometric mean diameter 1.84 mm, sphericity 0.47, and projected area 5.18 mm². For S_2 seeds with a moisture content of 4.45%, the values are: length 3.61 mm, width 1.46 mm, thickness 0.82 mm, geometric mean diameter 1.62 mm, sphericity 0.45, and projected area 4.55 mm². In general, all measured dimensional properties of S_1 seeds were found to be higher compared to S_2 seeds. It has been reported that in the study conducted on onion seeds, the average length, width, and projection area of the seeds in the control group were determined to be 1.52 mm, 1.06 mm, and 1.26 mm², respectively (Dumanoğlu and Çakmak 2019). According to research findings, (Tang et al. 2015) reported the length, width, and thickness values for tomato seeds as 3.33 mm, 2.36 mm, and 0.63 mm, respectively. For cabbage seeds with 8.24% moisture content, the length, width, and sphericity values were reported as 2.03 mm, 1.79 mm, and 0.85, respectively (Jadhav et al. 2017).

In terms of shape characteristics, the width/length (W/L) ratio was determined to be 0.43±0.011 for seeds from the S_1 local population and 0.41±0.011 for seeds from the S_2 population. Both populations were classified as having long seeds. Regarding shape characteristics, the L/3 values for seeds from the S_1 and S_2 populations were found to be 1.32 and 1.20, respectively. These values were lower than 1.65 and 1.46 (W), indicating that the seeds fell into the oval category.

Table 4. Dimensional properties of bare seeds S_1 and S_2 population

Properties	S_1 seeds	S_2 seeds
Moisture (m.c.d.b.) (%)	%3.96	%4.45
Length (mm)	3.95±0.067	3.61±0.071
Width (mm)	1.65±0.027	1.46±0.029
Thickness (mm)	0.98±0.031	0.82±0.028
Geometric mean diameter, (mm)	1.84±0.025	1.62±0.026
Sphericity (Ø)	0.47±0.006	0.45±0.008
Projected area (mm²)	5.18±0.102	4.55±0.119

To compare the length, width, thickness, geometric mean diameter, and sphericity values between the two black carrot seed populations, relationships were established. For the S_1 local population seeds, the relationships are:

$$L = 2.394 \times W = 4.031 \times T = 2.147 \times GMD = 8.404 \times Ø$$

For the S_2 population, the relationships are:

$$L = 2.473 \times W = 4.402 \times T = 2.228 \times GMD = 8.022 \times Ø$$

The coefficients of correlation for these relationships show provided in Table 5. In the S_1 population, the relationships between L/T, L/GMD, and L/Ø were statistically significant, while in the S_2 population, the relationships between L/GMD and L/Ø were statistically significant

Table 5. The correlation coefficients of black carrot seeds of S_1 and S_2 population

Variety	Particulars	Ratio	Degrees of freedom	Correlation coefficient
S_1 seeds	L/W	2.394	48	-0.1262
	L/T	4.031	48	0.3755**
	L/GMD	2.147	48	0.6603**
	L/S	8.404	48	-0.6485**
S_2 seeds	L/W	2.473	48	0.0896
	L/T	4.402	48	0.0265
	L/GMD	2.228	48	0.4628**
	L/S	8.022	48	-0.6631**

**p>0.01

Similar results were obtained in the research conducted with okra seeds, and high correlation coefficients were found between L/T, L/GMD, and L/Ø values (Çalışır et al. 2005).

Some physical properties of black carrot seeds are detailed in Table 6. For S_1 population seeds, the volume, thousand grain weight, bulk density, and terminal velocity values were found to be 2.01 mm^3, 2.51 g, 0.431 gcm^{-3}, and 1.80 m s^{-1}, respectively. In comparison, S_2 population seeds had lower values of 1.37 mm^3, 2.21 g, 0.395 g cm^{-3}, and 1.75 m s^{-1}, respectively. The static coefficient of friction values for S_1 seeds on galvanized sheet iron, steel sheet, and plastic surfaces were 0.620, 0.664, and 0.706, respectively, while for S_2 seeds, these values were higher at 0.674, 0.743, and 0.789, respectively. The higher static coefficient of friction for S_2 seeds is attributed to their lower sphericity and fuzzy structure. According to the results of studies conducted with vegetable seeds, similar results were obtained in terms of physical properties. In the study conducted with tomato seeds, the thousand seeds weight was found to be 2.8 g and the critical velocity was 3.78 m s^{-1} (Tang et al. 2015). Additionally, it was reported that at a moisture level of 9.94%, the thousand-seed weight, critical velocity, and bulk density values of tomato seeds were 2.63 g, 2.67 m s^{-1}, and 0.3 g cm^{-3}, respectively (Jadhav et al. 2017).

Table 6. Physical properties of black carrot seeds of S_1 and S_2 population at 3.96 and 4.45% (m.c.d.b)

Properties	S_1 seeds	S_2 seeds
Volume (mm^3)	2.01±0.090	1.37±0.077
Thousands seeds weight of carrot (g)	2.51±0.234	2.21±0.034
Bulk density (g cm^{-3})	0.431±0.0136	0.395±0.007
Terminal velocity (m s^{-1})	1.80±0.019	1.75±0.019
Static coefficient of friction		
Galvanized sheet iron	0.623±0.020	0.674±0.024
Steel sheet,	0.664±0.018	0.743±0.022
Plastic	0.692±0.023	0.789±0.028
Color characteristics		
L	46.18±0.961	51.41±0.656
a*	4.70±0.068	4.59±0.249
b*	16.23±0.341	18.23±0.683

When considering parameters in the commonly used CIELAB system, the L, a, and b values for seeds from the S_1 and S_2 populations were found to be 46.18 and 51.41, 4.70 and 4.59, and 16.23 and 18.23, respectively. It can be observed that while the values are close, the S_2 population has a slightly brighter (higher L value) and more yellowish (higher b value) color. These minor differences, despite the overall similarity in color between the two populations, can provide distinguishability under specific lighting and color conditions.

3.2. Germination properties of black carrot seeds

Seed germination is an estimate of the viability of a population of seeds. The higher the FGP value, the greater the germination of a seed population. The bare black carrot seeds from the S_1 and S_2 populations have been observed to complete germination in 10 and 9 days, respectively. This indicates that the germination period of seeds from the S_1 population is one day longer than that of the seeds from the S_2 population (Fig. 2). The final germination percentage of bare black carrot seeds obtained from S_1 and S_2 populations was found to be respectively. For certification requirements, it is desired that the germination percentages of standard carrot seeds do not fall below 75% (Anonymous 2022b).

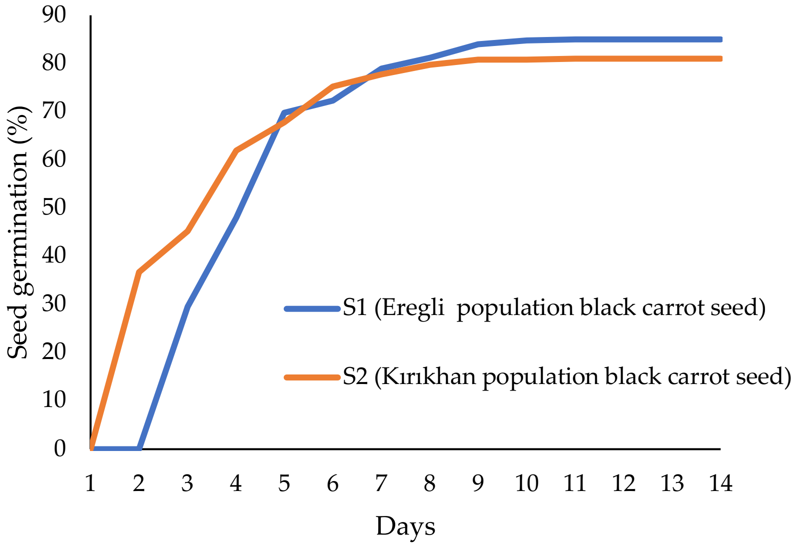

Figure 2. Cumulative seed germination of uncoated S_1 and S_2 black carrot seeds

Therefore, the black carrot seeds obtained from the two local populations fall into the standard seed group. As a result of the variance analysis applied to the germination values, no statistical difference was found among the black carrot seeds (Table 7).

Table 7. Germination parameters of black carrot seeds

Seeds	FGS (%)	MGT (day)	GI -	GRI (% day^{-1})	CVG -
S_1 (Ereğli)	84.75	4.52$_a$	548.5	20.85$_a$	22.20$_a$
S_2 (Kırıkhan)	80.75	3.50$_b$	574.0	28.52$_b$	28.79$_b$
Standard error of the mean (SEM)	0.0171	0.1606	20.33	0.8540	1.035
P-value	0.066	0.004	0.409	0.001	0.004

MGT is an accurate measure of the time taken for a lot to germinate but does not correlate this well with the time spread or uniformity of germination. The lower the MGT, the faster a population of seeds has germinated (Orchard, 1977). The Mean Germination Time (MGT) values for seeds from the S_2 population were found to be an average of 3.50 days, while the MGT values for seeds from the S_1 population were found to be an average of 4.52 days. This difference in MGT values was found to be statistically significant (Table 7). In a study conducted under laboratory conditions with seeds from different basil populations, the average germination time values were reported to range between 2.17 and 2.25 days (Dumanoğlu and Mokhtarzadeh 2021). Additionally, the average germination time of anise seeds from the Turkish line was reported to be 5.25 days (Dumanoğlu et al., 2020).

In Germination Index (GI), seeds that germinate on the first day are given maximum weight, while seeds that germinate later are given progressively less weight. Therefore, the GI emphasizes both the germination percentage and the speed of germination. A higher GI value indicates a higher germination percentage and rate (Benech Arnold et al. 1991). The Germination Index (GI) values for black carrot seeds from the S_2 and S_1 populations were found to be 574 and 548.5, respectively. Although the GI was higher in the S_2 variety, this difference was found to be statistically insignificant.

The GRI reflects the percentage of germination on each day of the germination period. Higher GRI values indicate higher and faster germination. Germination Rate Index (GRI) was determined to be 20.85 %.day^{-1} for seeds from the S_1 population and 28.52 %. day^{-1} for seeds from the S_2 population. This difference was found to be statistically significant.

The Coefficient of Velocity of Germination (CVG) gives an indication of the rapidity of germination. It increases when the number of germinated seeds increases, and the time required for germination decreases.

Theoretically, the highest possible CVG is 100, which would occur if all seeds germinated on the first day (Jones and Sanders 1987). The CVG value for black carrot seeds from the S_2 population was 28.96, while the CVG value for seeds from the S_1 population was lower at 22.20. This difference was found to be statistically significant.

4. Conclusions

Recognizing the physical properties of black carrot seeds is essential for mechanization applications such as storage, cleaning, grading, coating, and sowing with pneumatic precision vegetable planters. Both populations of black carrot seeds were found to have a long and oval shape. The seeds from the S_1 population have greater values in terms of length, width, thickness, geometric mean diameter, and projected area compared to the S_2 seeds. Specifically, these values for S_1 seeds are 3.95 mm, 1.65 mm, 0.98 mm, 1.84 mm, and 5.18 mm^2, respectively, whereas for S_2 seeds they are 3.61 mm, 1.46 mm, 0.82 mm, 1.62 mm, and 4.55 mm^2, respectively. The sphericity, which indicates how close the shape of the seed is to a sphere, was found to be slightly higher in S_1 seeds (0.47) compared to S_2 seeds (0.45). S_2 seeds have lower values for volume (1.37 mm^3), thousand grain weight (2.21 g), bulk density (0.39 g cm^{-3}), and terminal velocity (1.73 m s^{-1}) compared to S_1 seeds. However, the static coefficient of friction values for S_2 seeds are higher on galvanized sheet iron (0.674), steel sheet (0.743), and plastic surfaces (0.789). The color values (L, a, and b) for seeds from the S_1 and S_2 populations were found to be 46.18 and 51.41, 4.70 and 4.59, and 16.23 and 18.23, respectively. Although the values are close, the S_2 population seeds are slightly brighter (higher L value) and more yellowish (higher b value) in color. The germination rate values of black carrot seeds were found to be 84.75% for the S_1 population and 80.75% for the S_2 population. The Mean Germination Time (MGT) values were 4.52 days and 3.50 days, respectively. The S_1 population shows a higher germination rate, while the S_2 population germinated in a shorter time. The GI value was found to be 574 for the S_2 variety and 548.5 for the S_1 population. In other words, we can say that the S_2 population germinates more quickly. The GRI value was 28.52 for the S_2 variety and 20.85 for the S_1 population, indicating that the germination percentage was higher each day during the germination period for the S_2 population. The Coefficient of Velocity of Germination (CVG) was 28.79 for the S_2 variety and 22.20 for the S_1 population, suggesting that the time required for germination is shorter for the S_2 variety. The data obtained from this research are expected to be helpful for future studies.

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Determination of Physical-Mechanical Properties of Leek Plant (*Allium porrum* L.)

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HIGHLIGHTS

- In this study, physical and mechanical properties were determined using different cutting angles (30°, 45°, 60°) with flat (non-serrated) and serrated knives.
- In the leek plant, the highest cutting force was observed in the different regions (top, middle, bottom) of the plant, showing regional variations.
- The study showed that knife type (flat vs. serrated) significantly affects the cutting force and mechanical properties of leek.
- Cutting angles (30°, 45°, 60°) were found to play a crucial role in the physical and mechanical properties of leek.

Abstract

Leek is a vegetable grown towards the end of summer and harvested during fall. It is commonly found in the Asian diet and is grown worldwide. Consumed both fresh and dry, the mechanical properties of a leek plant need to be well-known with regard to the studies related to its production, processing, packaging, transport, and agricultural mechanization applications. This study aims to define the physical and mechanical properties of the leek plant (*Allium porrum L.*) used for agricultural purposes in Turkey. Conducted with different types of knives (flat, serrated) and different shearing angles (30, 45, 60°), shearing force, bio-yield force, rupture force, energy in rupture force, deformation, shearing stress, stress in rupture force, stiffness values have been determined for three different sections of leek plant. Furthermore, colour measurements have been performed for each section of the leek plant at three different heights. The highest shearing, bioyield force, and rupture force values have been defined respectively as 66.27±3.52, 53.02±2.82 and 48.15±33.71 N during the shearing made with a flat knife. The highest consumed energy value has been defined as 1.10±0.09 J in the studies conducted with the flat knife, while the lowest value has been defined as 0.23±0.12 J in the studies carried out with the serrated knife. The lowest deformation value was 25.37±1.18 mm in the experiments performed at a 45° knife angle with a serrated knife.

Keywords: Leek; Mechanization; Physico-mechanical properties,Turkey

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1. Introduction

In the lands of our country, suitable for ecologic structure and the agricultural production potential, where 81.5% of the 23.2 million hectare total cultivated area consists of field crop cultivation, greenhouse growing and fruit growing, while vegetables are grown in 3,4% (784 thousand hectares) of the cultivated area. In terms of most consistent vegetables over the years in terms of production and price, leek plant is one of the leading ones. Due to the inhibitory properties of Allium vegetables, it is thought to reduce the risk of prostate cancer, colorectal cancer, stomach cancer and breast cancer (Hsing et al. 2002). Leek (*Allium ampeloprasum L.*) is a rich source of secondary metabolites, including phenolic acids, flavonoids, and flavonoid polymers, which have significant health benefits. Leek exhibits various health benefits such as anti-asthma, antiseptic, diuretic, antibacterial, antioxidant, and antifungal properties. It is also beneficial in protecting the skin against damage and reducing the risk of gastrointestinal diseases diseases (Bernaert et al. 2014; Shahrajabian et al. 2021).

Leek is a commonly grown vegetable with significant benefits to human health. In previous times leek was being consumed during the winter only and it was produced accordingly, however, the possibility of growing it in each season has nowadays made it almost a year-long vegetable.

Leek (*Allium porrum L.*), similar to onion and garlic, is a member of Allium variety and Alliceae family, produced in wide areas and in great quantities in Turkey and from time to time it is also exported in fresh form, too (Figure 1). Leek is a vegetable that can be grown in every season and mostly grown for its leaves and stalk. In Turkey it is mostly consumed as a winter vegetable but it can be cultivated in almost all regions as it is not a picky vegetable in terms of climate. In Mediterranean and Aegean Regions it can be left on field surface in winter season and harvested at any time (Altunkanat 2019).

Leek is making up a significant part of winter vegetable consumption in Turkey. Leek production in Turkey takes place in an approximate area of 8.000 ha annually and production figure in 2018 was 252.958 ton (TÜİK 2020).

Along with an increased demand to vegetables in food sector, vegetable prices have a continuous tendency of increasing in the whole world and in recent years total yield in vegetable production has increased by 30-35%. Further to these, leek can be exported by being dried or frozen, all of which makes it possible that leek production will keep growing (Abak et al. 2010).

Figure 1. Summer and winter leek plants

Mechanization applications are being employed within agricultural production activities such as harvesting, threshing, transporting, cleaning, industrial processing and packaging. However, these applications are not fulfilled properly and this leads to loss and damaging of products. Such drawbacks need to be decreased and mechanization applications need to be increased and developed to achieve high yield and quality production. Furthermore, characteristics of an agricultural product need to be well-understood to ensure that agricultural products lose their properties at a minimal level during the post-harvest processes (Babayiğit 2010). For many years, studies have been concentrating on the field of harvest mechanisation of cereals and legumes. However, the number of studies on mechanization practises used in harvest and post-harvest processes in vegetable cultivation is not sufficient. The development and increase of such practises require a good knowledge on the mechanical properties of vegetables that are consumed both fresh and dry. The purpose of this study is to determine the mechanization related physical and mechanical properties of leek plant (*Allium porrum L.*) used for agricultural purposes in Turkey. Conducted by using different knife types (flat, serrated) and different knife cutting angles (30, 45, 60°), This study revealed key mechanical properties of the leek plant, including shearing force, bioyield force, and rupture force. Additionally, energy in rupture point, shearing stress, deformation, and stiffness values were determined across three different sections of the plant. Studies took place with 3 repetitions at 700 mm/min knife speed. Furthermore, colour measurements have been taken for each section at 3 different heights of the leek plant.

2. Materials and Methods

As an experimental material, 'İnegöl 92' variety, a summer leek plant (*Allium Porrum L.*) has been used in this study. Summer varieties are in light-green colour, they have soft textures, shorter lifespans and are more vulnerable against cold. Their stem lengths are 2-3 times longer than the winter varieties can extend up to and 80 cm (Anonym 2013). Materials acquired from the market have been brought to Isparta University of Applied Sciences, Faculty of Agriculture and analysed in Harvest Technologies Laboratory.

In the study, the weight, stalk diameter, and stalk length values of the leek, which may be important in mechanization applications, were determined. The leek plant is divided into 3 sections, which are upper, middle, and lower sections, starting from the root and extending to the point where the leaves start bending (Figure 2). Diameter values of Sections A, B, C have been defined, and cutting took place with three repetitions for each section. Stalk diameter is an important and practical parameter to characterise the leek plant. Stem diameter must be known to define the stress occurring on the plant. The impact on stress values by diameter values at different heights needs to be known (Khan et al. 2010).

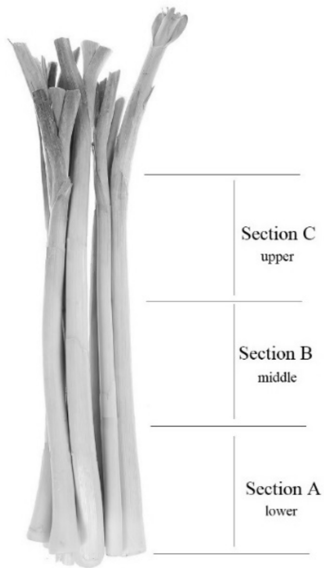

Figure 2. Definition of leak stem.

The physico-mechanical properties of a biologic material are being use for harvest and post-harvest processing to design harvest, transport, storage and grinding machines (Yılmaz et al 2015). Measurements to determine the physical and mechanical properties have been conducted by using a LLoyd (Lloyd Instrument LRX Plus, Lloyd Instruments Ltd, An AMATEK Company) biologic material test device (Figure 3). This device consists of a platform it has been placed in and a moving part, a unit making the movement possible and a data processing unit. The data processing unit consists of a load cell with 500 N capacity, a computer with a

NEXYGEN Plus software where data is transmitted. The technical specifications of the device are provided in Table 1.

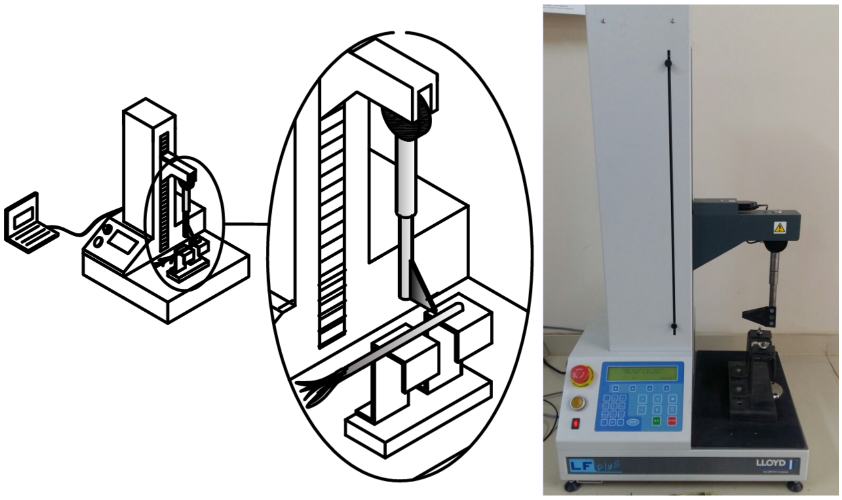

Figure 3. Biologic material test device

Table 1. Technical specifications of the biological material testing device

MODEL	LFPlus
Maximum Load Capacity	1 kN
Movement Speed	0.05-1270 mm/min
Speed Accuracy	<0.2%
Measurement Distance	500 mm
Application Accuracy	Less than 0.005% of the used load cell
Extension Measurement Accuracy	<1.3 microns
Data Storage Rate	8 kHz
Extensometer Input	Digital and Analog
Data Output	Digital RS232, Analog 10V DC max. (Optional)
Measurement System	Complies with BS EN ISO 7500:1999, ASTM E4, DIN 51221 standards
Analysis Software	NEXYGEN FM, NEXYGEN MT Data Analysis Software, and Ondio Software for Advanced Applications
Power Supply	115/230V AC ±10% 50-60 Hz
Weight	46 kg

Experiments in the study have been conducted with 3 repetitions on 3 different heights of plant stalk by using 2 types of knives and 3 different knife angles (Figure 3). Shearing force, rupture force, and deformation were measured using a high-precision testing machine (e.g., Lloyd Instrument LRX Plus) equipped with a calibrated load cell. Leek samples were secured in the apparatus, and the shearing process was conducted at 30°, 45°, and 60° angles. Force-displacement data was recorded in real-time to identify peak and rupture forces, which occurred when the leek structure failed. Deformation was measured by tracking the displacement of the blade through the leek, calculated as the difference between the initial and final positions of the blade, ensuring accurate capture of minimal deformations.

Figure 3. Colorimeter used in experiments

By shearing the leek plant at horizontal plane, its mechanical properties such as stalk shearing force, bioyield force, rupture force, shearing stress, deformation, stress in rupture point, deformation in rupture point, energy in rupture point and stiffness have been defined. Furthermore, L, a* and b* values of Sections A, B and C have been defined by using PCE-CSM colorimeter (Figure 4). The technical specifications of the device are provided in Table 2. CIE Lab is being widely used for the colour measurement of colour space products. CIE Lab colour space has three coordinates. L* value represents black for 0.0, white for 100.0, a* value represents green if negative and red if positive, and b* value represents blue if negative and yellow if positive (Kuş et al. 2017; Çetin 2019).

Figure 4. Colorimeter used in experiments

Table 2. The technical specifications of PCE-CSM colorimeter

Geometry	8°/d
Aperture	Ø 6 mm
Sensor	Silicon photoelectric diode
Color spaces	CIE L*a*b*C*h, CIE L*a*b, CIE XYZ
Color difference formula	ΔE*ab, ΔL*ab, ΔE*C*H
Observation Angle	CIE 10°
Light source / device	D65/ LED blue light
Errors between each equipment	≤0.80 ΔE*ab
Repeatability	Standard deviation within ΔE*ab 0.08; Average of 30 measurements of standard white plate
Power supply	Rechargeable lithium-ion battery; 3.7 V @ 3200-mAh
Lamp life	5 years, more than 1.6 million measurements
Storage conditions	Air temperature: 0 ... 40°C / 32 ... 104°F; Air humidity: 0 ... 85% RH, non-condensing

3. Results and Discussion

In this study, the mechanical properties of leek (*Allium porrum* L.) were investigated using different knife types (flat and serrated) and cutting angles (30°, 45°, 60°). The results indicate that the cutting force, bio-yield force, rupture force, rupture energy and deformation of the leek plant vary significantly depending on the knife type and cutting angle.

The lengths of the leek plants which have been subjected to cutting experiments at different harvest heights range between 31-65 cm. Average weight value of leek plant has been defined as 89.56 g. Plant stalk average diameter values calculated as per shearing heights (Sections A, B and C) are given in Table 3. The average brightness value of leek (*Allium porrum L.*) samples used in the study has been defined as (L*) 60.96±13.27, a* value has been defined as 3.49±0.60 and b* value has been defined as 28.44±10.91.

Table 3. Diameter values of leek stem based on cutting heights

Average plant size (cm)	Shearing Heights	Diameter (mm)		
		Average (mm)	Standard Deviation	Variation Coefficient (%)
48.6	Section A	15.84	4.41	27.86
	Section B	14.68	4.21	28.66
	Section C	13.83	4.16	30.04

The diameter values of leek stalk which has been cut at different cutting heights have ranged between 8.07-25.50 mm. Average diameter values in Sections A, B and C have been respectively defined as 15.84±4.41, 14.68±4.21 and 13.83±4.16 mm. A decrease has been observed in the diameter values, depending on plant structure, starting from root and extending to the point where the leaves start making an angle with the stalk.

The results show that flat knives require more cutting force during the shearing process compared to serrated knives. This finding is consistent with the study by Khan et al. (2010), which reported that flat knives encounter greater resistance than serrated knives, primarily due to the latter's ability to better engage the fibrous structure of the plant. The lower cutting force of the serrated knife is attributed to its efficiency in cutting through the fibers with less resistance, thus reducing the overall mechanical load during cutting (Yilmaz et al., 2015). These findings are consistent with the recent work of Petitkan et al. (2019), who also observed that the type of cutting tool significantly affects the mechanical properties of the plants. Mechanical properties of the plant stalk observed through experiments conducted with a flat knife with 3 different cutting angles (30, 45, 60°) and different harvest heights are given in Table 4.

Table 4. Average cutting parameters of plant stalk in different cutting heights and knife angles (flat knife)

Shearing Height	Shearing Angle	Shearing Force	Bio-Yield Force	Rupture Force	Energy in Rupture Point	Deformation	Shearing Stress	Stress in Rupture Force	Stiffness
		(N)	(N)	(N)	(J)	(mm)	(MPa)	(MPa)	(N/mm)
Section A	30°	66.27 ±3.52	53.02 ±2.82	47.19 ±7.63	1.10 ±0.09	38.41 ± 3.78	0.26 ±0.06	0.18 ±0.02	7.13 ±1.56
	45°	61.97 ±34.71	49.58 ±27.77	48.15 ±33.71	0.70 ±0.58	27.25 ±4.48	0.22 ±0.03	0.16 ±0.04	8.02 ±1.36
	90°	60.91 ±18.09	48.72 ±14.47	47.21 ±13.19	1.09 ±0.84	41.30 ±3.82	0.23 ±0.13	0.17 ±0.10	7.58 ±3.52
Section B	30°	59.50 ±14.69	47.60 ±11.75	37.52 ±26.70	0.72 ±0.29	41.18 ± 1.97	0.22 ±0.04	0.13 ±0.09	5.58 ±1.40
	45°	52.70 ±21.88	42.16 ±17.51	36.03 ±26.74	0.50 ±0.28	30.55 ± 2.62	0.23 ±0.09	0.11 ±0.04	5.23 ±1.80
	90°	48.93 ±27.25	39.14 ±21.80	36.98 ±19.14	0.51 ±0.43	36.89 ±7.83	0.19 ±0.13	0.14 ±0.10	5.69 ±1.31
Section C	30°	40.34 ±9.87	32.27 ±7.90	25.62 ±8.83	0.43 ±0.16	43.06 ±1.45	0.15 ±0.04	0.10 ±0.03	4.61 ±0.82
	45°	36.92 ±19.78	29.54 ±15.83	21.01 ±19.53	0.26 ±0.23	29.53 ±4.87	0.16 ±0.08	0.06 ±0.05	4.41 ±1.49
	90°	46.16	36.92	31.76	0.39	42.41	0.17	0.11	5.45

		±8.44	±6.76	±4.56	±0.05	±1.49	±0.08	±0.05	±1.92

As the plant shearing height increased (Sections A, B and C) in experiments conducted with a flat knife in different cutting angles, a decrease in shearing force, bioyield force, rupture force, consumed energy and stress values has been observed, depending on diameter values. Highest shearing and bioyield force values have been observed as 66.27±3.52 and 53.02±2.82 N respectively in Section A at 30° cutting angle. The highest rupture force has been observed as 48.15±33.71 N in Section A in experiments conducted at 45° cutting angle. Energy values consumed for cutting have been observed to be higher in experiments conducted at 30° and 90° cutting angles in Section A. The highest energy value in rupture point has been observed as 1.10±0.09 J while the lowest value has been observed as 0.26±0.23 J in Section C with a 45° cutting angle. Studies have shown that the peak force and specific energy required to cut vegetables are heavily influenced by the knife edge angle and the texture of the vegetable. Our findings indicate that a lower cutting angle, such as 30°, requires higher shearing force due to increased fiber engagement in the leek stalk. This observation is supported by Singh et al. (2016), who demonstrated that lower knife edge angles, particularly at low cutting speeds, result in higher resistance and specific energy requirements when cutting vegetables with diverse textures.

Deformation during the shearing process was measured using a test device that recorded the movement of the blade as it cut through the leek. Deformation was calculated as the difference between the initial and final positions of the blade, ensuring that even small changes in the structure of the leek were accurately captured. An increased amount of deformation has been observed in plant stalk in cutting experiments conducted with 30° and 90° cutting angles. An increase in leek stalk stiffness value is leading to decreased deformation. The lowest deformation amount has been observed as 27.25±4.48 mm in Section A with a 45° cutting angle. The surface graphic which shows the interactions between cutting parameters of flat knife experiment and cutting height and cutting angle is given in Figure 5.

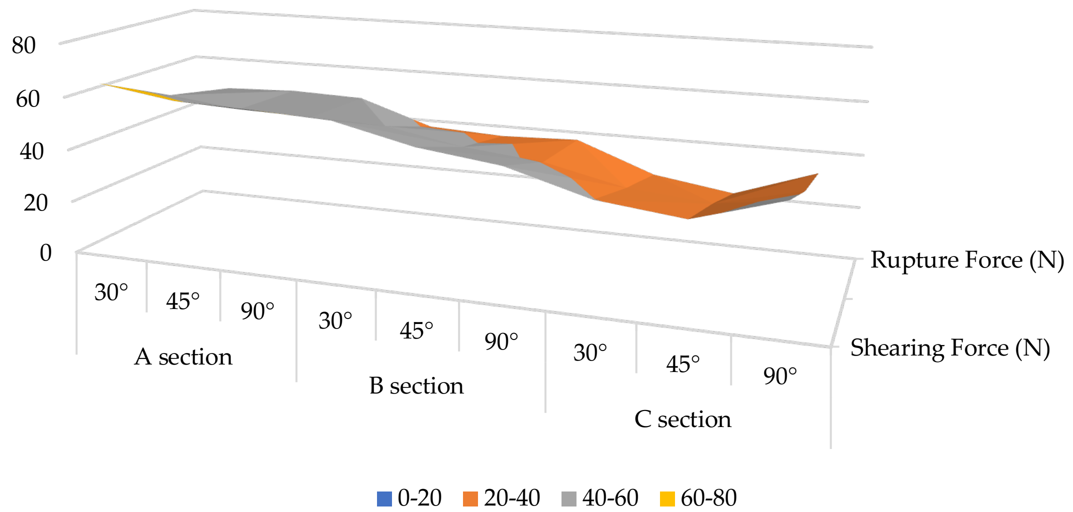

Figure 5. The interaction between cutting parameters of flat knife experiment and cutting height and cutting angle

The figure effectively illustrates the significant effect of both cutting angle and section height on the mechanical properties of the leek. The results suggest that a 45° cutting angle provides a balanced approach that minimizes both shear and fracture forces at different section heights, while a 30° angle requires the highest forces due to increased fiber engagement. These findings are critical for optimizing cutting techniques in agricultural practices to achieve efficiency while maintaining product integrity.

Mechanical properties of the plant stalk cut by serrated knife in 3 different cutting angles (30, 45, 60°) and in different harvest heights is given in Table 6.

Table 6. Average cutting parameters of plant stalk in different cutting heights and cutting angles (serrated knife)

Shearing Height	Shearing Angle	Shearing Force	Bio-Yield Force	Rupture Force	Energy in Rupture Point	Deformation	Shearing Stress	Stress in Rupture Force	Stiffness

		(N)	(N)	(N)	(J)	(mm)	(MPa)	(MPa)	(N/mm)
Section A	30°	47.70 ±14.01	38.16 ±11.21	23.38 ±12.32	0.54 ±0.20	41.61 ± 1.57	0.28 ±0.08	0.13 ±0.02	4.75 ±0.96
	45°	46.56 ±6.74	37.25 ±5.40	20.70 ±9.86	0.44 ±0.01	25.37 ±1.18	0.39 ±0.08	0.17 ±0.07	4.50 ±0.90
	90°	61.03 ±18.09	48.82 ±14.47	22.75 ±13.19	0.70 ±0.46	49.63 ±1.41	0.51 ±0.12	0.16 ±0.13	5.14 ±0.93
Section B	30°	38.58 ±9.89	30.86 ±7.91	24.24 ±8.05	0.39 ±0.13	44.57 ± 2.35	0.23 ±0.04	0.14 ±0.02	4.12 ±0.89
	45°	43.36 ±15.40	34.69 ±12.32	22.21 ±11.45	0.38 ±0.14	27.21 ± 1.73	0.36 ±0.15	0.25 ±0.14	3.79 ±0.95
	90°	54.33 ±20.23	43.47 ±16.18	20.73 ±24.64	0.57 ±0.33	53.28 ±4.07	0.40 ±0.03	0.14 ±0.14	4.44 ±1.23
Section C	30°	30.55 ±12.78	24.44 ±10.23	21.71 ±3.72	0.23 ±0.12	44.71 ±2.06	0.17 ±0.01	0.13 ±0.04	3.15 ±1.16
	45°	36.64 ±12.99	29.31 ±10.39	16.10 ±12.11	0.32 ±0.12	29.58 ±2.16	0.31 ±0.12	0.13 ±0.09	3.51 ±0.94
	90°	46.74 ±21.24	37.39 ±16.99	21.44 ±25.16	0.44 ±0.27	53.45 ±0.56	0.35 ±0.09	0.16 ±0.15	4.29 ±1.32

In experiments conducted with serrated knife, decrease has been observed in shearing and bioyield force values as the cutting height of leek plant increased. However, the same values have been observed to be high again in experiments conducted with a 90° cutting angle. The highest shearing and bioyield force values have been observed in Section A at 90° cutting angle as 61.03±18.19 and 48.82±14.47 N, respectively. Plant stalk rupture force value has been observed to be higher, 24.24±8.05 N, at the mid-part of the plant stalk (Section B). Energy values in rupture point were lower in Section C, while the highest value has been observed in Section A of the plant stalk as 0.70±0.46 J when cut by a 90° cutting angle. With regards to the experiments conducted by using a serrated knife, the highest shearing stress value has been observed in Section A by 0.51±0.12 MPa at 90° cutting angle, while the highest stress in rupture point has been observed in Section B by 0.25±0.14 MPa at 45° cutting angle. And the amount of deformation that occurred as a result of cutting with a serrated knife has showed a tendency to increase, in parallel to the increase in cutting height and the amount of deformation decreases as plant stiffness decreases. The lowest deformation amount has been observed, again, in Section A as 25.37±1.18 mm in experiments conducted at 45° cutting angle. The surface graphic which shows the interactions between cutting parameters of serrated knife experiment and cutting height and cutting angle is given in Figure 6.

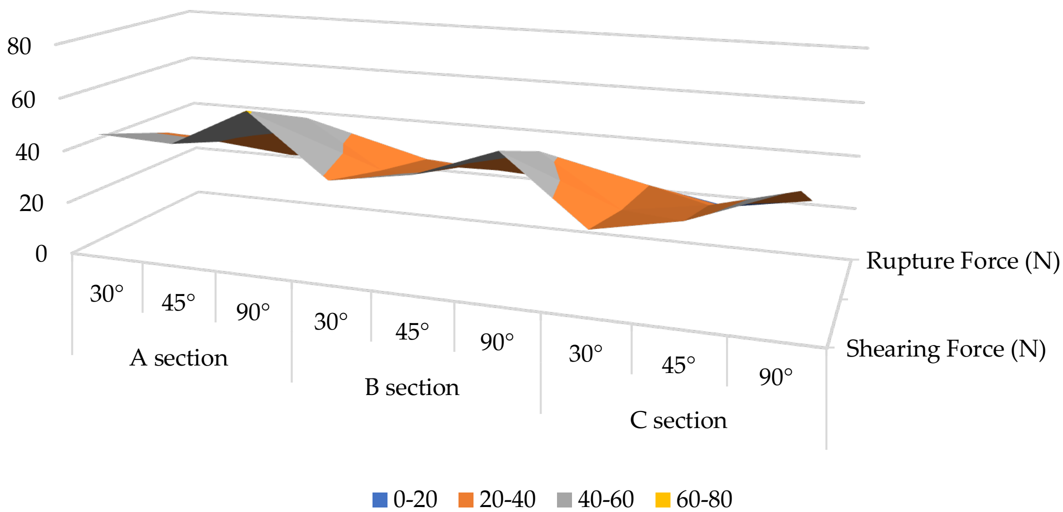

Figure 6. The interaction between cutting parameters of serrated knife experiment and cutting height and cutting angle

The figure clearly demonstrates the benefits of using a serrated knife for cutting leek, particularly in terms of reducing the required shearing and rupture forces. The results indicate that a 45° angle may be the most efficient for cutting across different sections of the leek, balancing force requirements and cutting precision. These findings can inform the selection of cutting tools and angles in both agricultural and industrial applications to optimize efficiency and product quality.

4. Conclusions

In this study, the effects of knife type and cutting angle on the mechanical properties of leeks were investigated in detail. Our results indicate that both factors significantly influence the efficiency and quality of the cutting process. According to study results, cutting parameters of leek plant vary depending on harvest heights and knife type. Shearing force, bio-yield force, rupture force, energy in rupture point and stiffness values of cutting actions at different stalk heights have been observed to be higher in experiments conducted with a flat knife than those conducted with a serrated knife. Deformation and stress values, on the other hand, are observed to be higher in experiments conducted with a serrated knife.

The comparison between flat and serrated knives showed that the serrated knife required less cutting force and improved the precision of the cut, minimizing tissue damage. This is attributed to the serrated knife's ability to better engage the fibers of the leek, thereby reducing the resistance encountered during cutting.

Furthermore, the analysis of the cutting angles showed that the angle at which the knife intersects the leek plays a key role in determining the mechanical response of the vegetable. Among the angles tested, a cutting angle of 45° was found to be optimal, balancing the applied cutting force and minimizing the deformation of the leek tissue. This suggests that knife orientation during cutting can be optimized to improve cutting efficiency and product quality.

In conclusion, this research highlights the importance of selecting appropriate cutting tools and angles to improve the mechanical processing of leeks. These findings can be useful for both agricultural practices and the food processing industry, contributing to improved cutting techniques and quality control. Future studies can explore the application of these findings to other vegetables and cutting scenarios, thereby extending the scope of this research

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Research Article

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Classification of Orange Features for Quality Assessment Using Machine Learning Methods

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HIGHLIGHTS

- Oranges are valued for their high vitamin C, sweet taste, fiber, and antioxidant qualities.
- Quality assurance is vital for orange market competitiveness and customer satisfaction.
- Traditional quality assessment methods are costly and prone to human error.
- The study found k-NN to be the most accurate algorithm for orange quality assessment at 69.38%.
- Machine learning improves orange quality control, benefiting consumers and producers.

Abstract

Oranges are a member of the citrus family and are eaten in large quantities due to their high vitamin C content, sweet and tart taste, and useful fiber and antioxidant qualities. Orange quality assurance is essential to market competitiveness and customer satisfaction. Conventional approaches to evaluating quality are costly and susceptible to mistakes made by people. This research investigates how well different machine learning algorithms automate and improve the orange quality assessment procedure. A dataset containing 241 samples and 11 features (size, weight, sweetness (Brix), acidity (pH), and color) was used to evaluate the effectiveness of the Random Forest (RF), XGBoost, and k-Nearest Neighbors (k-NN) algorithms. According to the findings, k-NN acquired the maximum accuracy of 69.38%, with RF coming in second at 67.34% and XGBoost third at 63.26%. These results demonstrate how machine learning models may be used to improve quality control in the orange industry by offering a more dependable and effective approach. According to this study, machine learning can significantly improve the quality control procedures for oranges, resulting in higher-quality goods for customers and more productivity for providers. The orange sector can enhance product quality and expedite operations by utilizing these technologies, eventually benefiting producers and consumers.

Keywords: Artificial Intelligence; Quality Classification; Orange Quality; Machine Learning Algorithms.

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1. Introduction

Orange is a fruit belonging to the citrus family and is usually orange in color and oval in shape. It contributes to strengthening the immune system with its abundant amount of vitamin C. With a sweet and sour flavor, oranges are mostly consumed fresh or used for juices and desserts. They are also rich in fiber and antioxidants, which have positive effects on digestive health and overall body function. In order to increase sales of orange fruits and improve market competitiveness, the selection of high quality oranges is of great importance (Cayuela and Weiland 2010). During this selection process, many criteria such as size, shape, acidity, sweetness and color are used to determine quality (Asriny et al., 2020). However, this process can still be time-consuming to perform manually and is vulnerable to human error. Therefore, the development of artificial intelligence technologies that automate the orange selection process and objectively determine quality can offer a more reliable and efficient system for both producers and consumers (Denata et al. 2021; Ganesh et al. 2019; Kumar et al. 2024). Literature reviews on the quality of oranges and external factors affecting the quality of oranges are included in this section:

Santiago et al. (2019) presented two different methods for assessing the freshness and caliber of oranges. In the first study, they classified fresh and rotten orange images with 78.57% accuracy using CNN algorithm. The second study classified oranges as small, medium and large using LDA and k-NN algorithms. The LDA algorithm outperformed k-NN with an overall accuracy of 82% and a kappa coefficient of 0.66 (Santiago et al., 2019). Ganesh et al. (2019) introduced a deep learning method called Deep Orange for orange detection and segmentation in orange groves. This method is based on the image segmentation framework Mask R-CNN. The system uses both RGB and HSV color information from images taken under natural light conditions from an orange grove in Florida. The addition of HSV data significantly improves the model's accuracy in orange identification. The accuracy increases from 89.47% when only RGB data is used to 97.53% when HSV data is added. The overall effectiveness of the system is measured by the F1 score of close to 89% using both RGB and HSV data (Ganesh et al. 2019). In another study, Asriny et al. (2020) used a Convolutional Neural Network (CNN) to determine the quality of oranges. They categorized the dataset into 5 classes according to the quality status of the orange. The dataset contains a total of 1000 orange images using a smartphone camera. For each class, it consists of 200 images divided into 60% training data, 20% validation data and 20% test data. In this study, they achieved the highest classification accuracy of 96% with CNN. Leelavathy et al. (2021) developed a method for assessing the freshness of orange fruits using a convolutional neural network (CNN). The dataset consists of fresh and rotten orange images. The CNN model obtained 78.57% accuracy for fresh and rotten oranges. Denata et al. (2021) developed an image-based classification system for the classification of orange varieties in Sambas Regency. The dataset used consists of 2250 images of oranges, including madu oranges, madu susu and siam oranges. They used AlexNet architecture based on Convolutional Neural Network (CNN) as a deep learning method. They allocated 1575 images for training and 675 images for testing. In total, 10 periods of training were performed, and one model was produced in each period. The best performance was achieved with the model obtained in the 9th period with 94.81% accuracy. Momeny et al. (2022) presented a robust and generalizable method for disease and maturity detection by fine-tuning pre-trained deep learning models. The dataset consists of 1896 images collected from the farm, categorized into 4 classes (immature, semi-mature, mature and black spot diseased). The results show that the fine-tuned ResNet50 model performs best with a learning replication strategy with 99.5% accuracy and 100% F-1 score measurement success when considering black spot diseased images as a positive class. In this study, Kumar et al. (2024), compared machine learning models for classification of orange diseases. They tested K-Nearest Neighbor (k-NN), Convolutional Neural Network (CNN) with MobilNetV2 architecture, Random Forest (RF) and Support Vector Machine (SVM) models on four disease classes, namely Black spot, Mingy disease, Healthy and Green crack. As a result, the CNN model using MobilNetV2 architecture showed the best performance in all disease categories with an accuracy of 98.22.

Machine learning algorithms can make predictions about quality by analyzing the physical and chemical properties of oranges. In this study, orange size, weight, sweetness (Brix), acidity (pH), softness, harvest time, ripeness, color, variety, presence of blemishes and overall quality are input and output data for machine learning models. Using this data, the quality of the orange can be predicted. The dataset used in the study consists of 11 features and 241 data. Random Forest, k-NN and XGBoost machine learning algorithms were used to predict the quality of oranges. Together with the results obtained, this study highlights the potential of machine learning algorithms to optimize quality control processes in the orange industry and increase the production of quality products. With this technology, consumers can get better quality products while producers can increase their productivity. In addition, the study analyzes the important characteristics that affect quality in the available dataset.

2. Materials and Methods

This study evaluates the performance of various machine learning algorithms for determining orange quality. The dataset used contains a total of 241 samples of 11 features. The continuous variables in the dataset were converted into categorical variables using the np.digitize() function. Then the dataset was divided into two parts, 80% training and 20% testing. Random Forest, k-NN and XGBoost algorithms were used to predict the data set. The prediction processes were compared by looking at the performance metrics results. Then, the strengths and weaknesses of the machine learning models were observed by looking at the confusion matrix results. The methodology of the study is shown in Figure 1.

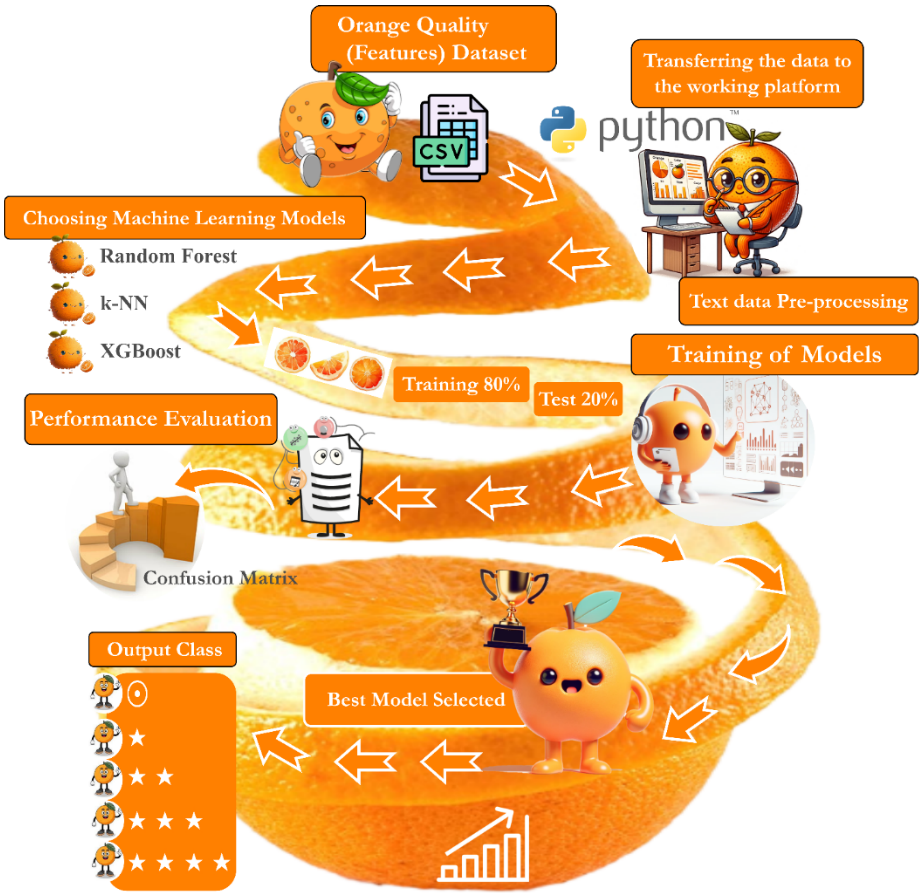

Figure 1. Flow Diagram for The Orange Classification Research

2.1. Dataset Description

The dataset "Orange Quality Analysis Dataset" contains 241 data with 11 different features. In Table 1 the dataset attributes and their description are presented for the Orange dataset. These attributes include numerical characteristics such as size, weight, sweetness (Brix), acidity (pH), softness, time of harvest and degree of ripeness. There are also categorical characteristics such as color, variety, presence of blemishes and overall quality (Shruthi 2024). The first five examples in the dataset are shown in Table 2. The dataset is divided into two separate sets, 80% train and 20% test, for quality estimation. The table describes various features of oranges along with their descriptions. The features include the size of the orange in centimeters, the weight of the orange in grams, the sweetness level measured in Brix, and the acidity level indicated by pH. Additionally, it covers the softness rating on a scale of 1 to 5, the number of days since harvest, and the ripeness rating also on a scale of 1 to 5 (1 represents the lowest and 5 for the highest rating value). Other characteristics listed are the fruit color, the variety of the orange, and whether there are any blemishes (Yes/No). The table also includes the overall quality rating of the orange, which serves as the target variable, rated on a scale of 1 to 5 (1 represents the lowest rating value and 5 represents the highest).

Table 1. Dataset Properties and Descriptions

No.	Features	Descriptions
1	Size	Size of orange in cm
2	Weight	Weight of orange in g
3	Brix	Sweetness level in Brix
4	pH	Acidity level (pH)
5	Softness	Softness rating (1-5)
6	HarvestTime	Days since harvest
7	Ripeness	Ripeness rating (1-5)
8	Color	Fruit color
9	Variety	Orange variety
10	Blemishes	Presence of blemishes (Yes/No)
11	Quality (Target)	Overall quality rating (1-5)

Table 2. First Five Samples of The Dataset

NO	Size (cm)	Weight (g)	Brix (Sweetness)	pH (Acidity)	Softness (1-5)	HarvestTime (days)	Ripeness (1-5)	Color	Variety	Blemishes (Y/N)	Quality (1-5)
0	7.5	180	12.0	3.2	2.0	10	4.0	Orange	Valencia	N	4.0
1	8.2	220	10.5	3.4	3.0	14	4.5	Deep Orange	Navel	N	4.0
2	6.8	150	14.0	3.0	1.0	7	5.0	Light Orange	Cara Cara	N	5.0
3	9.0	250	8.5	3.8	4.0	21	3.5	Orange-Red	Blood Orange	N	3.5
4	8.5	210	11.5	3.3	2.5	12	5.0	Orange	Hamlin	Y (Minor)	4.5

2.2. Random Forest

The Random Forest algorithm is a widely used ensemble method for classification and regression problems in machine learning (Koklu et al. 2012; Yong 2019). Random Forest is a tree-based learning method (Sarica et al., 2017) that combines multiple decision trees to create a more powerful model (Cinar et al. 2023; Yildiz et al., 2024a). The benefits of Random Forest algorithms as redusing the overfitting, aiding in feature selection, ensembility provided to be a popular algorithm and used for the classification. The Random Forest architecture is shown in Figure 2 (Yasin and Koklu 2023). In this study, the parameter settings for the Random Forest algorithm are n_estimators=100, random_state=42 and class_weight='balanced'.

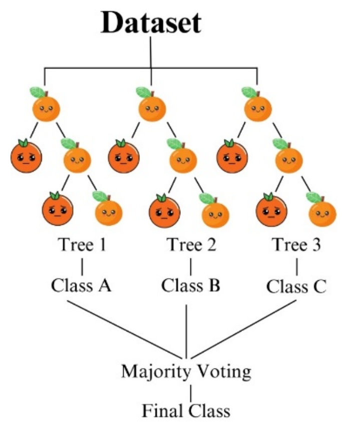

Figure 2. Random Forest Architecture

2.3. k-NN (k-Nearest Neighbors)

k-Nearest Neighbors (k-NN) is a simple and fundamental machine learning algorithm used for classification and regression problems (Cinar et al. 2023; Koklu et al. 2022). k-NN is classified as an instance-based learning method and travels around the surrounding neighbors of data to make predictions (Guo et al. 2003; Yildiz et al. 2024b). The k-NN architecture is shown in Figure 3. In this study, the neighbours parameter is set to 5 for the k-NN algorithm.

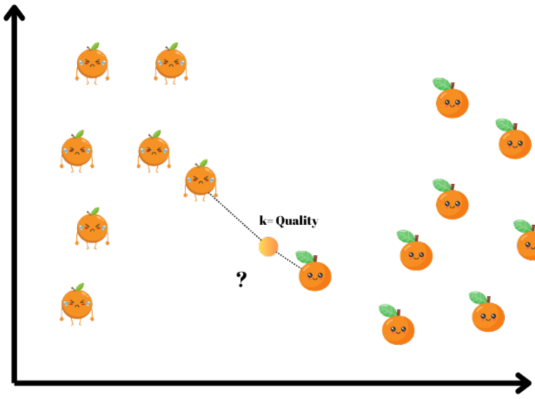

Figure 3. k-NN Architecture

2.4. XGBoost

XGBoost (Extreme Gradient Boosting) can be used for both classification and regression problems. XGBoost is based on an ensemble learning technique called Gradient Boosting. Ensemble learning (Koklu et al. 2014; Tutuncu et al. 2022) is the combination of multiple weak predictors (such as decision trees) into a stronger model. Gradient Boosting works by training weak predictors sequentially, with each predictor trying to correct the errors of the previous predictor (Chen and Guestrin 2016). In this study, default parameter settings were made for the XGBoost algorithm. The XGBoost architecture is shown in Figure 3.

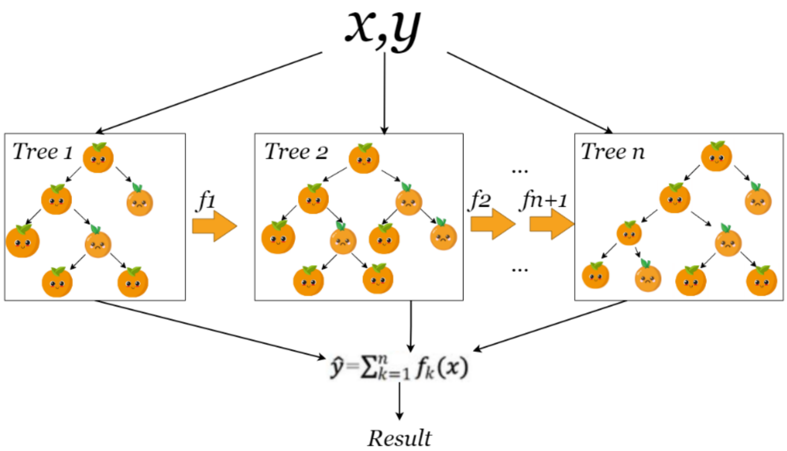

Figure 4. XGBoost Architecture.

2.5. Confusion Matrix and Performance Metrics

Confusion matrix is a table used to evaluate the performance of a classification model. This table provides a comparison between the actual and predicted classes of the model (Tutuncu et al. 2022). Confusion matrix is very useful for visually analyzing classification results and contributes to the calculation of many performance metrics (Gencturk et al. 2024; Heydarian et al. 2022). The two-class confusion matrix and multiclass confusion matrix are shown in Figure 5 and Figure 6. TP is the number of instances that the model correctly classifies as positive, TN is the number of instances that the model correctly classifies as negative, FP is the number of instances that the model incorrectly classifies as positive, FN is the number of instances that the model incorrectly classifies as negative.

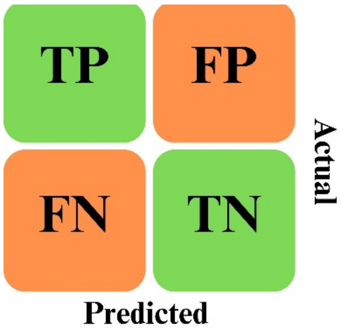

Figure 5. Two Class Confusion Matrix

	Predicted					
	C_1	C_2	C_3	...	C_n	
C_1	T_1	F_{12}	F_{13}	...	F_{1n}	Actual
C_2	F_{21}	T_2	F_{23}	...	F_{2n}	
C_3	F_{31}	F_{32}	T_3	...	F_{3n}	
...	...	...	...	...	...	
C_n	F_{n1}	F_{n2}	F_{n3}	...	T_n	

Figure 6. Muti Class Confusion Matrix

Performance metrics are measures used to evaluate the success of a machine learning model. Various metrics can be used to evaluate the performance of a model (Kursun et al. 2023; Tutuncu et al. 2022). The formulas of performance metrics are shown in Table 3.

Table 3. Formulas of Performance Metrics

Metrics	Formula	
Accuracy	$\frac{\sum_{i=1}^{1} \frac{tp_i + tn_i}{tp_i + fn_i + fp_i + tn_i}}{l}$	(1)
Precision	$\frac{\sum_{i=1}^{1} \frac{tp_i}{tp_i + fp_i}}{l}$	(2)
Recall	$\frac{\sum_{i=1}^{1} \frac{tp_i}{tp_i + fn_i}}{l}$	(3)
F1-Score	$\frac{2 * \frac{\sum_{i=1}^{1} \frac{tp_i}{tp_i + fp_i}}{l} * \frac{\sum_{i=1}^{1} \frac{tp_i}{tp_i + fn_i}}{l}}{\frac{\sum_{i=1}^{1} \frac{tp_i}{tp_i + fp_i}}{l} + \frac{\sum_{i=1}^{1} \frac{tp_i}{tp_i + fn_i}}{l}}$	(4)
Mean Square Error	$\frac{1}{N}\sum_{i=1}^{N}(y_i - \acute{y}_i)^2$	(5)

2.6. Correlation Matrix

A correlation matrix is a matrix that measures the relationship between each pair of features in a dataset. This relationship is usually determined using statistical measures such as the Pearson correlation coefficient. The correlation matrix is an important tool for understanding the relationships between variables in a data set, assessing how variables are related to each other, and transforming or modeling variables when necessary (Steiger 1980). A value close to -1 in the matrix indicates a strong negative correlation between the two attributes. If the value is closer to 0, there is a weak correlation between the two attributes. If the value in the matrix is close to 1, there is a strong positive correlation (Lorenzo-Seva and Ferrando 2021).

3. Results

This section may be divided by subheadings. It should provide a concise and precise description of the experimental results, their interpretation, as well as the experimental conclusions that can be drawn.

In this section, 3 different models created with different machine learning algorithms to determine orange quality are analyzed. The dataset used to determine orange quality consists of 241 samples and 11 features.

Random Forest, k-NN and XGBoost algorithms were used to predict this dataset. The obtained accuracy and Mean Square Error (MSE) values are shown in Table 4 and the correlation matrix result is shown in Figure 6.

Table 4. Accuracy Presentation for Used Machine Learning Algorithms

	Random Forest	k-NN	XGBoost
Accuracy (%)	67.34%	69.38%	63.26%
Precision	73.91%	67.99%	64.52%
Recall	67.34%	69.38%	63.26%
F-1 Score	67.89%	68.43%	63.61%
MSE	0.55	0.55	0.77

In this section, we compare the performance of different machine learning algorithms for predicting orange quality. The results show that the k-NN algorithm stands out in this field by providing the highest accuracy rate 69.38%. This shows that the k-NN algorithm is able to predict orange quality in the best way and is more reliable in this area compared to other algorithms. In addition, the Random Forest algorithm achieved a precision value of 73.91%, indicating that the model has a high probability of accurately predicting orange quality. The Random Forest algorithm ranked second after k-NN with a classification accuracy of 67.34%. This result shows that the Random Forest algorithm is also successful in predicting orange quality. However, the XGBoost algorithm showed a lower performance compared to the other two algorithms with a classification accuracy of 63.26%. This shows that the XGBoost algorithm is not as successful as the other two algorithms in predicting orange quality.

k-NN and Random Forest algorithm obtained an MSE value of 0.55, indicating that the mean squared error between the predictions of the model and the actual values is low. This shows that k-NN and Random Forest algorithms are the algorithms that predict orange quality well. However, the XGBoost algorithm has a higher error rate compared to the other two algorithms with an MSE of 0.77. This again shows that the XGBoost algorithm is not as successful as the other two algorithms in predicting orange quality. Correlation matrix values are given in Figure 7. In Figure 8 the confusion matrix values illustrated.

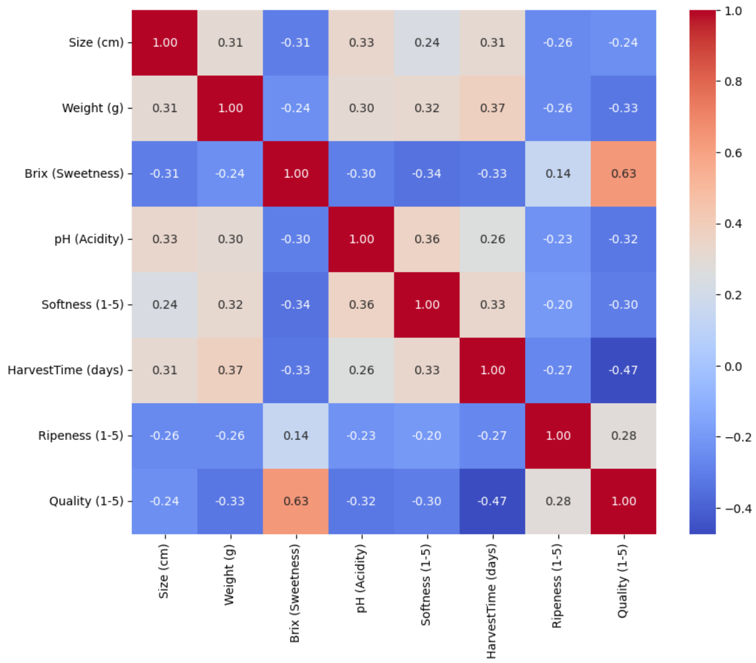

Figure 7. Correlation Matrix Result

When the correlation matrix given in Figure 7 is examined, it is seen that the most important feature affecting quality is Brix (Sweetness) with a correlation value of 0.63. In other words, the higher the taste value of the orange, the higher the quality grade. Then there is a strong and negative relationship between HarvestTime and Quality with a correlation value of -0.47. The correlation values of Weight (-0.33), pH (-0.32) and softness (-0.30) are very close to each other. According to the observations, "Weight," "pH," and "softness" have an inverse effect on the quality of oranges. As the values of these three attributes increase, the quality of the orange decreases. "Size" and "ripeness" have weak correlation values. It cannot be said that they affect orange quality as much as other variables.

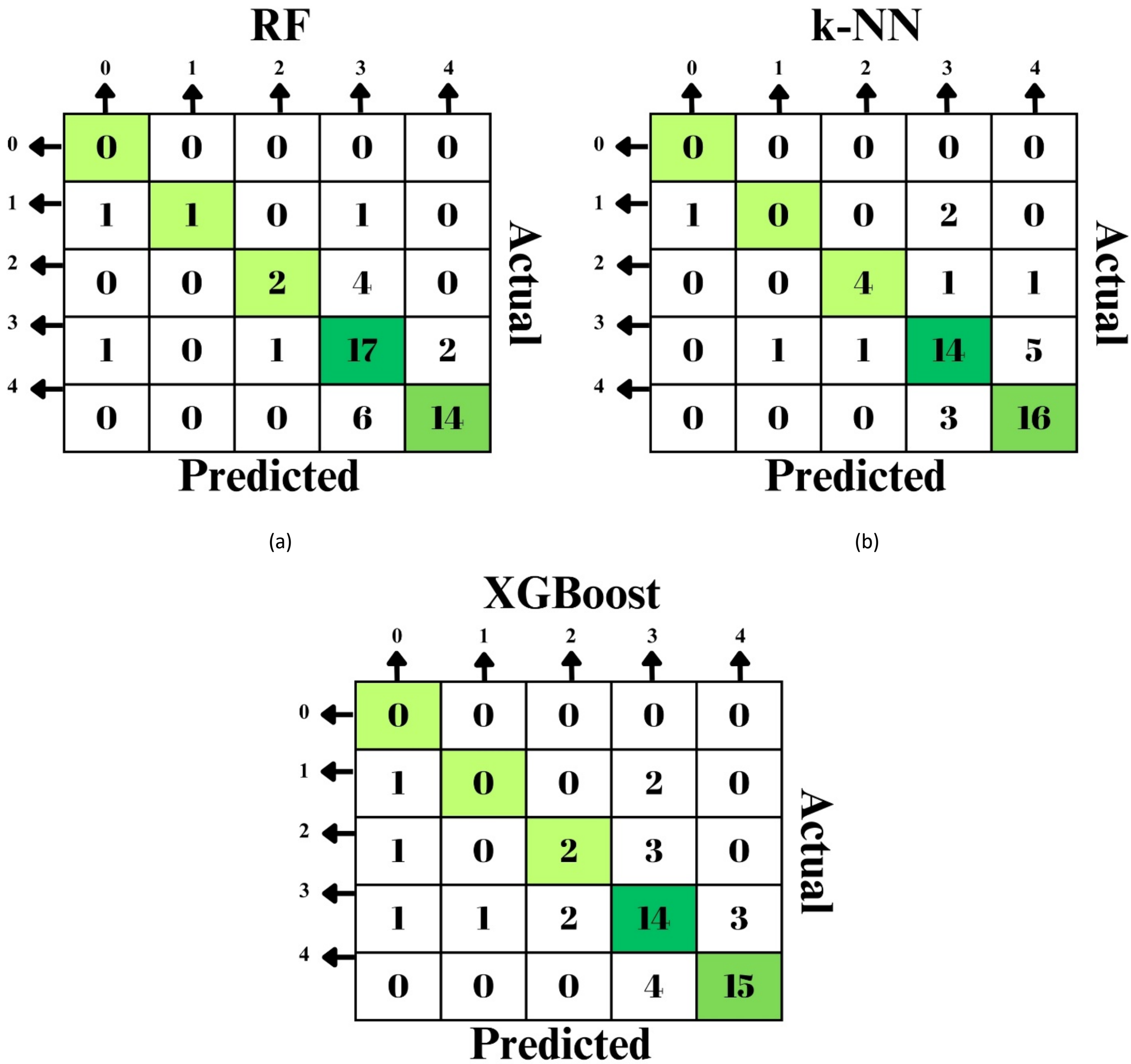

Figure 8. Confusion Matrix Results

When the confusion matrix results are analyzed, it is seen that k-NN is the algorithm that most accurately predicts the quality oranges in the dataset. However, it is observed that Random Forest and XGBoost algorithms confuse oranges with quality values of 2 and 3. This indicates that these two algorithms perform more poorly in distinguishing oranges of certain quality levels.

4. Discussion and Conclusions

Random Forest, k-NN and XGBoost machine learning algorithms were used to make predictions on the orange quality dataset. Each of these algorithms attempted to predict orange quality by capturing different features and patterns in the dataset in different ways. Random Forest used a method of decision trees and combined the prediction of each tree to create a robust prediction model, while k-NN used a similarity-based approach to predict the label of a sample based on its surrounding neighbors. XGBoost used gradient boosting to combine weak prediction models into a strong prediction model.

We used the np.digitize function to convert the continuous variables in the dataset to categorical. We performed this step because we wanted to categorize continuous variables into specific categories when preparing input data for regression or classification models. We categorized each sample categorically according to thresholds.

In the future, orange quality detection systems developed using this technology can scan agricultural fields more effectively and detect poor quality or diseased oranges, thus reducing agricultural labor and time loss and increasing productivity. At the same time, accurate and timely diagnostics can reduce the amount of pesticides needed, which can contribute to the spread of environmentally friendly agricultural practices. Machine learning and artificial intelligence techniques can also offer solutions to more complex agricultural problems. Trait engineering studies can be conducted to identify traits that affect orange quality. Perhaps better results can be obtained by creating new traits or transforming existing traits. Such studies can provide valuable guidance to orange growers and industry experts to make more accurate and reliable decisions.

Based on the results of the study, it seems that machine learning algorithms can be used effectively in predicting orange quality. It is thought that these algorithms can provide important information to orange producers in quality control processes and help them to improve quality

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Identification of Leaf Diseases from Figs Using Deep Learning Methods

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- HIGHLIGHTS
- Early detection of plant diseases is crucial for agricultural health and productivity.
- The study uses AI for early fig plant disease detection to minimize agricultural losses.
- Fig leaves dataset includes 1350 diseased and 971 healthy leaf images.
- The study compares DarkNet-19, ResNet50, VGG-19, and other algorithms for disease detection.
- VGG-19 achieved the highest accuracy at 93.32%, highlighting AI's potential in agriculture.

Abstract

Early detection of plant diseases is of great importance for agricultural production and plant health. Early detection is important to prevent the spread of diseases and reduce agricultural losses. The aim of this study is to use artificial intelligence technologies for the early detection of diseased fig plants and reduce agricultural losses. The fig leaf dataset used in the study has two classes: healthy and diseased leaves. There are a total of 2321 images in the dataset. Among these images, there are 1350 images representing diseased leaves and 971 images representing healthy leaves. The dataset is divided into 80% training data and 20% test data. DarkNet-19, ResNet50, VGG-19, VGG-16, ShuffleNet, GoogLeNet, MobileNet-v2, EfficientNet-b0, and DarkNet-53 algorithms were used to analyze the fig leaves dataset using a MATLAB graphical user interface (GUI). The classification accuracy values of each algorithm are as follows: DarkNet-19 90.3%, ResNet50 90.95%, VGG-19 93.32%, VGG-16 92.89%, ShuffleNet 89.44%, GoogLeNet 87.5%, MobileNet-v2 87.5%, EfficientNet-b0 85.56%, and DarkNet53 91.59%. These results evaluate the usability and performance of different algorithms for the early detection of plant diseases. The research emphasizes the importance of the effective use of artificial intelligence technologies in the agricultural industry.

Keywords: Data Analysis; Deep Learning Methods; Disease Detection; Image Classification; Fig Leaves Diseases

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1. Introduction

Plant diseases are a growing challenge in the global agricultural industry, causing significant economic losses (Kursun et al. 2024). Monitoring plant health and detecting diseases early is used to prevent disease spread and facilitate effective management practices (Martinelli et al. 2015). Early detection of plant diseases can facilitate the treatment of diseased plants and increase the productivity of plant production (Kursun et al. 2023b). This helps to minimize the damage caused by disease in the agricultural sector and to obtain healthy products.

Detection of diseases with image processing in the agricultural sector is becoming increasingly popular. With the developing image processing techniques, the use of image processing in the agricultural sector is increasing and developing (Yasin et al. 2023). This technology enables the processing of images captured by computers using various analysis techniques and producing the desired information. Image processing plays a role in solving many problems in the agricultural sector (Kursun et al. 2023a). In particular, it facilitates agriculture in issues such as the classification and detection of crop diseases. With these techniques, diseased plant parts such as leaves can be identified, affected areas can be measured and diseases can be diagnosed (Alzoubi et al. 2023).

Especially the protection of fruits against diseases is of great importance, such as figs, which are widely consumed and play an important role in agricultural production. Early detection of fig leaf diseases is important for efficient production. What artificial intelligence and image analysis techniques can be used for fast and accurate detection of fig leaf diseases is examined. Artificial intelligence-based systems and computerized image processing methods can play an important role in the identification and classification of diseases in fig fields. The integration of these technologies can enable fig producers to respond to diseases faster and increase agricultural productivity (Sharma et al. 2020).

The classification of fig leaves represents a significant area of focus in agricultural research, driven by the objective of enhancing productivity and minimizing human errors. The correct identification and classification of fig leaves can lead to improved disease detection, better crop management, and ultimately, higher yields. In this study, we explore the application of convolutional neural network (CNN) classification algorithms to achieve accurate fig leaf classification. The algorithms tested on the used interface include a diverse array of models: DarkNet-19, ResNet50, VGG-19, VGG-16, ShuffleNet, GoogLeNet, MobileNet-v2, EfficientNet-b0, and DarkNet-53. Each of these models has been selected for their proven efficacy in image classification tasks and their varying architectural approaches, which provide a comprehensive comparison of their performance in the context of fig leaf classification.

This research aims to use deep learning techniques to develop a robust system for the automatic classification of fig leaves. By evaluating the performance of multiple CNN architectures, the study seeks to identify the most effective algorithm in terms of accuracy, computational efficiency, and adaptability to different environmental conditions. The implications of this research are far-reaching, offering potential advancements in precision agriculture where accurate plant classification can inform better decision-making and resource allocation.

This work represents a thorough investigation into the use of deep learning for fig leaf classification. By systematically comparing the performance of various CNN models, we aim to determine the optimal algorithm that not only achieves high classification accuracy but also demonstrates practical applicability in real-world agricultural settings. This study is poised to contribute significantly to the field of agricultural informatics, paving the way for more intelligent and automated farming practices.

Presently, the classification of healthy and diseased plant leaves is becoming an important area of research in the food industry and agriculture. In particular, studies on plant materials such as fig leaves, as well as leaves of other vegetables and fruits, are of importance for plant health and consumer health. Research in this field is also carried out on many other plant species, for example tomato, cotton, rice, or various fruit leaves.

Bari et al. (2021), used the Faster R-CNN algorithm for real-time detection of rice leaf diseases. Faster R-CNN presents an advanced region recommendation network (RPN) architecture for detection. This model is trained with publicly available online resources and real field rice leaf datasets and achieves good results in terms of accuracy. The proposed deep learning-based approach is able to automatically diagnose distinctive rice leaf diseases such as rice blast, brown spot, and hispa with accuracies of 98.09%, 98.85%, and 99.17%, respectively. Moreover, the model is able to identify healthy rice leaves with 99.25% accuracy.

De Luna et al. (2018), trained a deep learning-based convolutional neural network for the detection of diseases such as Phoma Rot, Leaf Miner and Target Spot in a specific tomato variety, Diamante Max. Using a dataset of 4,923 images of healthy and diseased tomato leaves, they developed a system to detect the presence or absence of these diseases. The trained convolutional neural network was successfully used to detect diseases in tomato plants. The anomaly detection model trained with F-RCNN produces 80% accuracy, while the disease recognition model trained with Transfer Learning achieves 95.75% accuracy. Using an automatic image capture system, they achieved 91.67% accuracy in recognizing diseases in tomato plant leaves.

Kumari et al. (2019), used the K-means clustering method to perform image segmentation of agricultural diseases. With this method, they identified the regions affected by the disease and extracted various features from these regions. The extracted features were used to classify the diseases. For cotton leaf diseases, the accuracy rates for bacterial leaf spot and target point detection were 90% and 80%, respectively. For tomato leaf diseases, they obtained 100% accuracy rate for septoria leaf spot and leaf mold detection.

In the study by Ozguven and Adem (2019), they highlighted the consequences of leaf spot disease (*Cercospora beticola* Sacc.) in the field causing yield loss in sugar beet. Timely detection of disease symptoms is important; disease progression can cause a loss of 10% to 50% of sugar yield. Therefore, early detection of disease symptoms and prompt treatment measures are necessary. The method proposed in this study was developed by modifying the R-CNN architecture. This method, which uses image-based expert systems, was trained and tested with 155 images. According to the test results, the overall correct classification rate of the proposed model was 95.48%.

Iqbal and Talukder (2020) emphasized that detecting Early Blight (EB) and Late Blight (LB), two important foliar diseases that commonly affect potato plants and inhibit growth, in the early stages can increase the productivity of potato crops. In this study, they propose an automated system based on image processing and machine learning that aims to identify and classify potato leaf diseases. In the study, they performed segmentation on 150 healthy, 150 Early Blight and 150 Late Blight potato leaf images obtained from a publicly available plant database. These images were processed with seven (Random Forest (RF), Logistic Regression (LR), k-Nearest Neighbors (KNN), Decision Trees (DT), Naive Bayes (NB), Linear Discriminant Analysis (LDA), Support Vector Machine (SVM)) classifier algorithms to recognize and classify diseased and healthy leaves. As a result of the analysis, they determined that the Random Forest classifier performed the best with an accuracy rate of 97%.

Zhong and Zhao (2020) proposed three regression methods based on DenseNet-121 deep convolutional network, multi-label classification and focus loss function for apple leaf disease identification. They used an apple leaf image dataset containing 2462 images of apple leaf diseases for data modeling and method evaluation. The proposed methods achieved 93.51%, 93.31% and 93.71% accuracy on the test set, respectively. These results showed that they outperformed the cross-entropy loss function (92.29% accuracy) based on traditional multiple classification methods.

Zhang et al. (2019), addressed the limitations of existing image-based crop disease recognition algorithms. The limitations of the proposed approach in the classification process are focused on segmenting diseased leaf images with K-means clustering, extracting shape and color features from lesion information, and classifying diseased leaf images using sparse representation (SR). In this study, they compared the proposed approach with four other feature extraction-based methods (probabilistic neural networks (PNNs), sparse representation classification (SRC), Deep CNNs (DCNNs), and AlexNet) using a leaf image dataset focusing on cucumber diseases. The results show that the proposed approach has an accuracy of 85.7% in recognizing seven major cucumber diseases.

Yıldız et al. (2024), examined the use of different algorithms such as k-Nearest Neighbors (KNN), Random Forest (RF), Logistic Regression (LR), Support Vector Machine (SVM) and Neural Networks (NN) on a dataset created from images of tomato leaf diseases. An algorithm developed in Python provided the highest accuracy. They obtained the highest accuracy rate of 95.6% in the classification process. In addition, classification with the deep learning model was performed with an accuracy rate of 96%.

Using a dataset of fig leaves, a study compares the performance of different deep learning models to classify healthy and diseased leaves. This study aims to help in the rapid detection of diseased leaves in the agricultural sector. The rapid detection of diseased leaves contributes to faster treatment of diseased plants, thus increasing agricultural productivity (Yasin & Koklu 2023; Yasin et al. 2024).

2. Materials and Methods

In this study, various deep learning algorithms were applied to classify healthy and sick fig leaves using fig leaves dataset from Mendeley Data. The deep learning models used include DarkNet-19, ResNet50, VGG-19, VGG-16, ShuffleNet, GoogLeNet, MobileNet-v2, EfficientNet-b0 and DarkNet-53. The dataset is divided into 80% training and 20% test dataset. This separation of training and test sets provides a consistent testing environment to evaluate the performance of the models. Each deep learning algorithm was trained on the training data and validated on the test data to classify healthy and sick leaves. The results are analyzed and compared according to performance metrics such as classification accuracy, precision and sensitivity of the different algorithms (Hafi Saad et al. 2023). The steps to be applied in the study process are given in Figure 1.

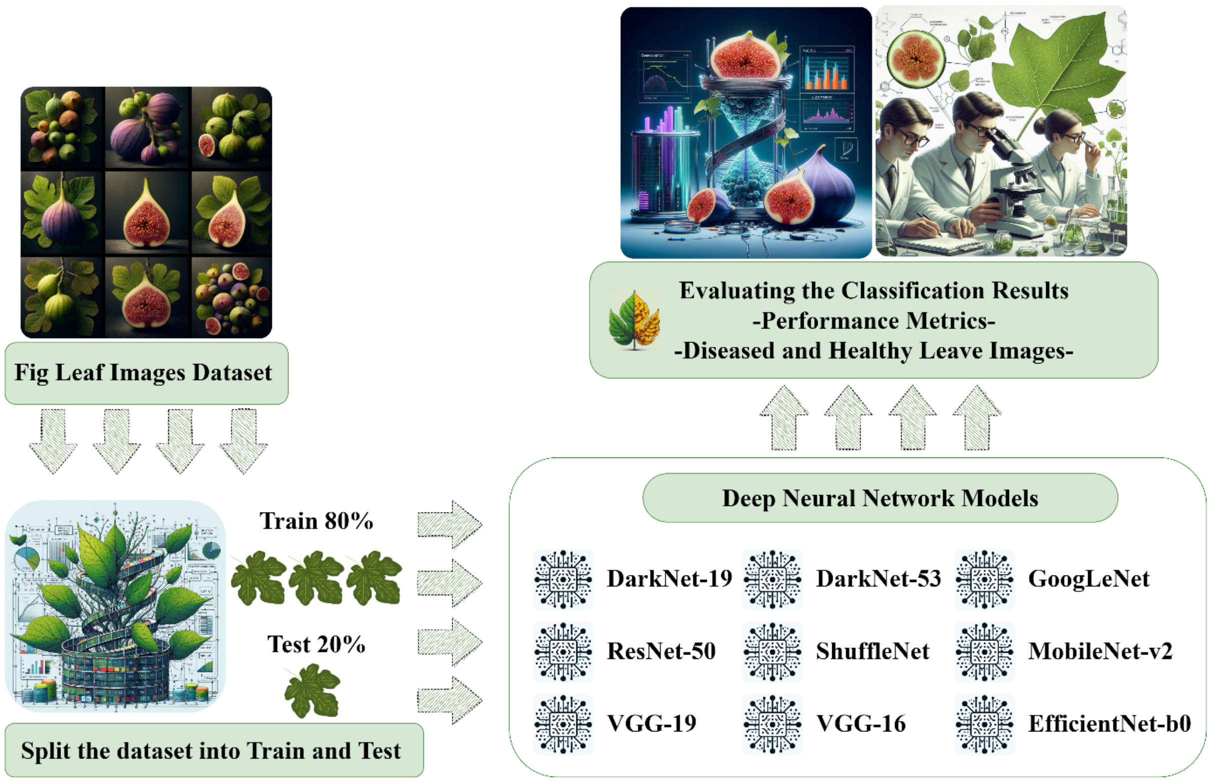

Figure 1. Fig leaf disease detection flow diagram

2.1. Dataset Description

"Fig Leaves Dataset" was used in this study. The dataset included healthy and diseased fig leaves, which were associated with Ficus leafworms. The dataset, obtained using the methods described in the paper, was used to study the health status of fig leaves and their association with Ficus leafworms. This dataset consists of high-resolution images that were precisely managed and acquired during the fruiting season. In total, the dataset contains 2321 images, with 1350 images representing infected leaves and 971 images depicting healthy ones. The images were acquired using a random sampling approach to ensure a balance between data from different fig trees and a detrimental mix of diversity. Sample images of the dataset are shown in Figure 2 (Hafi et al. 2024).

Healthy fig's leaves (a)	Diseased fig's leaves (b)

Figure 2. Sample images of fig dataset

2.2. Convolutional Neural Network

The Convolutional Neural Network (CNN) is making significant achievements in the field of deep learning and attracting great attention in industry and academia. CNN is achieving impressive successes in image processing, natural language processing and many other areas. These achievements allow computers to understand and analyze complex visual data (Cinar & Taspinar 2023). CNN's wide range of applications and impressive performance have increased and are increasing its popularity in deep learning research and industrial applications (Li et al. 2021).

ResNet-50: ResNet is an important type of deep learning neural network introduced by Kaiming He, Xiangyu Zhang, Shaoqing Ren and Jian Sun in 2015 in the paper "Deep Residual Learning for Image Recognition". This neural network has attracted attention by using a "residual learning" approach to facilitate the training of deeper networks. Compared to the ResNet-152 model, which had 152 layers in its first implementation, ResNet-50 has a smaller layer architecture. ResNet-50 has been trained in more than one million images and uses high-quality features learned from the ImageNet database. This model is a CNN and has a depth of 50 layers (Saritas et al. 2023). From one layer to the next, it passes the values needed to reach the result through predictions. To improve prediction accuracy, ResNet-50 has a special block structure that improves the quality of the results (Hayta et al. 2023; He et al. 2016).

EfficientNet-b0: EfficientNet is based on a base network developed using the AutoML MNAS framework. This network is fine-tuned to achieve maximum accuracy, but the computational load of the network is penalized if it is too large. Also penalized is the slow inference time, which is the time required for the network to make predictions. The architecture uses a mobile reverse bottleneck convolution similar to MobileNet-v2, but much larger in size due to the FLOPS (Total Loss Per Operation) increase. This base model is designed by a scaling strategy used to achieve a family of scaled EfficientNets. EfficientNet-b0 is a CNN algorithm developed to provide high performance and efficient computation in modern deep learning systems (Tan & Le 2019).

ShuffleNet: ShuffleNet is a highly efficient Convolutional Neural Network (CNN) model introduced in the paper "ShuffleNet: An Extremely Efficient Convolutional Neural Network for Mobile Devices" is a highly efficient Convolutional Neural Network (CNN) model. This model is specifically designed for use on mobile devices and aims to provide high accuracy while minimizing computational cost. ShuffleNet is optimized for mobile applications and works effectively in mobile environments with features such as low memory usage, low computational cost and fast inference time (Zhang et al. 2018).

DarkNet-19: DarkNet-19 is a convolutional neural network 19 layers deep. The network works with images of size 256x256 pixels. This network has been trained on more than one million images from the ImageNet database. Using a pre-trained model, it is able to classify images of 1000 object categories such as keyboard, mouse, pencil and many animals (Baygin et al. 2022).

GoogLeNet: "Going Deeper with Convolutions" is a research paper published in 2014 in collaboration between Google and several universities. In this paper, GoogLeNet (or Inception V1), a new architecture for increasing the depth of convolutional neural networks, was introduced. This architecture achieved great success by winning first place in the ILSVRC 2014 image classification competition (Cinar 2023). The overall architecture of Google Net has a depth of 22 times and is designed to prioritize computational efficiency. The basic idea of the architecture is that it can be run efficiently even on individual devices with low computational resources. It also includes two auxiliary classifier layers based on the Inception (4a) and Inception (4d) layers (Szegedy et al. 2015).

MobileNet-v2: MobileNet is a lightweight computer vision model. Open-sourced by Google, this computer vision model is specifically designed for training classifiers. MobileNet-v2 leverages deep convolutions using significantly fewer parameters compared to other networks, leading to a lightweight and efficient deep neural network. MobileNet-v2 is the first mobile computer vision model from TensorFlow (Howard et al. 2017; Koklu et al. 2022).

DarkNet-59: DarkNet-59 is a deep learning algorithm designed for computer vision applications. This algorithm is optimized for object recognition, classification and detection. DarkNet-59 is a customized version of the Darknet network architecture that underpins the YOLO (You Only Look Once) object detection systems. The DarkNet-59 algorithm is a 59-layer deep convolutional neural network. This network is designed with a special focus on speed and efficiency (Redmon & Farhadi 2018).

VGG-16: VGG-16 is an important convolutional neural network (CNN) model in the field of deep learning and computer vision. It was developed by the Visual Geometry Group (VGG) at the University of Oxford. VGG-16 is considered a fundamental reference point among deep convolutional neural networks and has a wide range of applications, especially in image classification tasks. VGG-16 model is a deep convolutional neural network with 16 layers (Koklu et al. 2023). These layers include 13 convolutional layers and 3 fully connected layers (Butuner et al. 2023; Simonyan & Zisserman 2014).

VGG-19: VGG-19 is a deep learning model for computer vision and was developed by the Visual Geometry Group (VGG) at the University of Oxford. The VGG-19 model is an extended version of the VGG-16 model and includes more convolutional layers. VGG-19 model is a deep convolutional neural network with a total of 19 layers (Koklu et al. 2023). These 19 layers include 16 convolutional layers and 3 fully connected layers (Simonyan & Zisserman 2014; Taspinar et al. 2022; Unal et al. 2022). The parameter values determined in all the algorithms used are shown in Table 1. These parameters follow common practices from earlier research and meet the needs of the models used. We also considered results from early tests, practical limits like computer power, and advice from experts.

Table 1. Parameter values used for fig leaf disease classification.

Parameter	Value
Validation Frequency	5
Max Epochs	8
Mini batch size	32
Initial learn rate	0.0001
Solver	sgdm
L2 Regularization	0.0001

2.3. Confusion Matrix and Performance Metrics

Confusion matrix is a type of matrix used to evaluate the performance of the model in classification problems. This matrix visualizes the relationship between the actual class labels and the class labels predicted by the model. Confusion matrix is used to analyze the accuracy, precision, recall rate and other performance measures of the model (Deng et al. 2016; Gencturk et al. 2024; Yildiz et al. 2024).

True Positive (TP): Represents true healthy outcomes. That is, the number of truly healthy samples that the model correctly predicts as healthy.

False Positive (FP): Represents samples that are truly diseased, but the model incorrectly predicts as healthy.

True Negative (TN): Represents true patient outcomes. That is, the number of truly sick samples that the model correctly predicted as sick.

False Negative (FN): Represents samples that are truly healthy but that the model incorrectly predicts as sick. These are missing healthy samples (Kursun et al. 2022; Yasin et al. 2023). An example table is shown in Table 2.

Table 2. Sample of binary confusion matrix.

		Actual Class	
		Healthy	**Infected**
Predicted	**Healthy**	**TP**	**FP**
Class	**Infected**	**FN**	**TN**

Confusion matrix is a tool used to evaluate the performance of classification models in more detail. This matrix visually shows the relationship between the model's actual class labels and the predicted class labels. By calculating various performance metrics with the values obtained from the confusion matrix, the performance of the model is analyzed in detail (Erdem et al. 2023; Koklu et al. 2012; Stehman 1997).

Accuracy: Indicates the proportion of correctly predicted samples in total samples. Accuracy measures the overall performance of the model.

$$\textbf{Accuracy} = \frac{TP+TN}{TP+TN+FP+FN} \quad (1)$$

Precision: Indicates the proportion of samples that the model predicts as healthy that are actually healthy. Precision focuses on reducing false positives (FP).

$$\textbf{Precision} = \frac{TP}{TP+FP} \quad (2)$$

Recall: Indicates the proportion of samples that the model predicts as healthy that are actually healthy. Precision is focused on reducing false positives (FP).

$$\textbf{Recall} = \frac{TP}{TP+FN} \quad (3)$$

F1-Score: The harmonic average of Precision and Recall. It is a balanced performance metric and focuses on both Precision and Recall in a balanced way.

$$\textbf{F1-Score} = 2 \times \frac{Precision \times Recall}{Precision+Recall} \quad (3)$$

3. Results

Two classes of fig data were used in this study. This dataset contains healthy and diseased fig leaves. In total, the dataset contains 2321 images, of which 1350 images represent infected leaves, and 971 images represent healthy leaves. The dataset is divided into 80% and 20%. 80% of the parts is used as training data and the algorithms are trained on this dataset. During the training process, the algorithms learn from the dataset and recognize patterns in it. After the training is complete, a 20% data set is used to test the performance of the model. This test data set is different from the data set used in the training process and is used to evaluate the generalization ability of the model.

The application is realized with deep learning methods. The deep learning algorithms used include DarkNet-19, ResNet50, VGG-19, VGG-16, ShuffleNet, GoogLeNet, MobileNet-v2, EfficientNet-b0 and DarkNet-53. These algorithms are used to accurately classify and understand the health status of fig leaves.

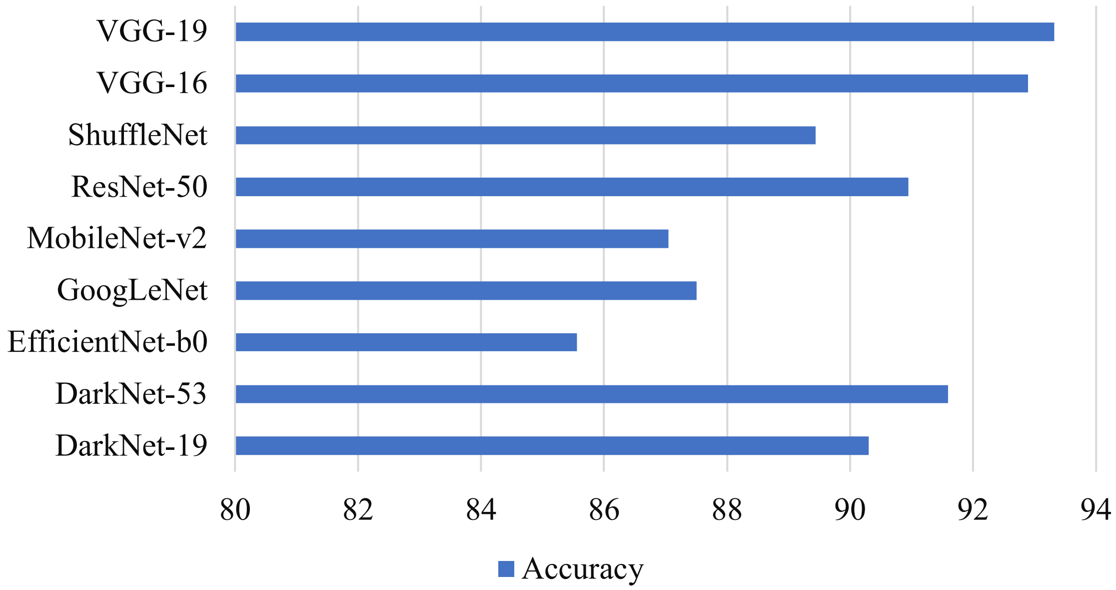

Figure 3. Accuracy values for the applied algorithms

In the deep learning methods, popular models such as DarkNet-19, ResNet50, VGG-19, VGG-16, ShuffleNet, GoogLeNet, MobileNet-v2, EfficientNet-b0, and DarkNet53 are evaluated. The classification accuracy values of each algorithm are as follows: DarkNet-19 90.30%, ResNet50 90.95%, VGG-19 93.32%, VGG-16 92.89%, ShuffleNet 89.44%, GoogLeNet 87.5%, MobileNet-v2 87.5%, EfficientNet-b0 85.56%, and DarkNet-53 91.59%.

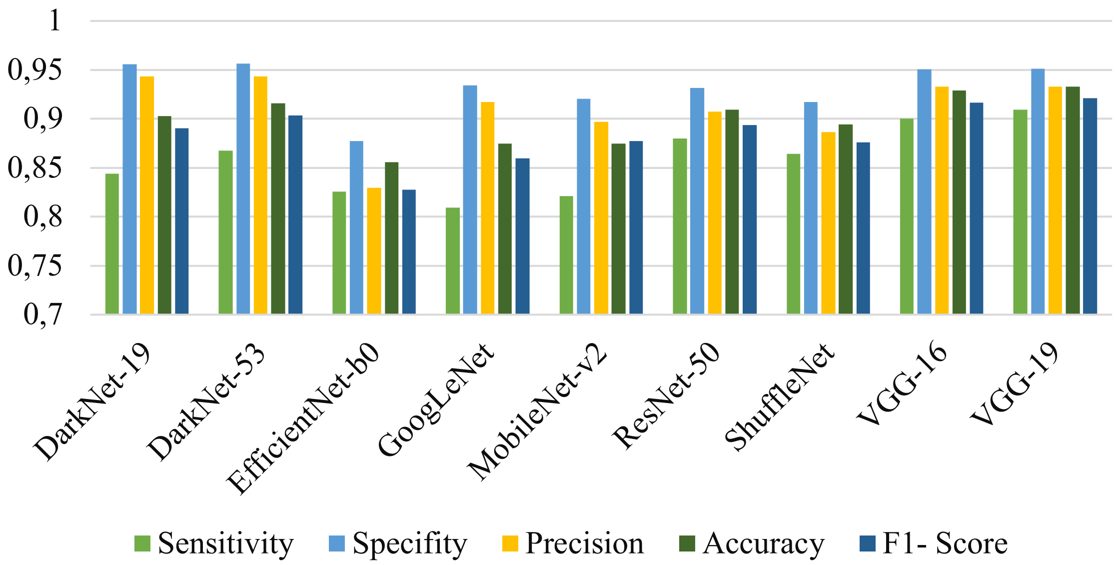

Figure 4. Performance metrics of the algorithm

Figure 4 shows performance metrics such as accuracy, precision, sensitivity and F1-score using the confusion matrix when working on a dataset of fig leaves classified as healthy or unhealthy. These values will help us to objectively evaluate the performance of your classification model. Each metric shows how successfully the model can distinguish between healthy and unhealthy classes and how reliable it can produce results.

In this study, it is noteworthy that the lowest accuracy results were obtained by GoogLeNet and MobileNet-v2 when deep learning algorithms such as GoogLeNet and MobileNet-v2 were applied to the dataset. The low accuracy performance of the GoogLeNet algorithm may be due to the complexity of the model's architecture. The GoogLeNet architecture has a depth of 22 times and has a complex and deep convolutional neural network structure. One of the reasons for such low results of GoogLeNet is the overall complexity of the model and its high demand on computational resources. Especially for lighter and simpler applications, lighter models such as MobileNet-v2 are preferred over GoogLeNet. MobileNet-v2 has an optimized architecture with low computational layers and can run more efficiently on mobile and local devices.

These results demonstrate the effectiveness of deep learning models for automatic recognition of leaf diseases. Models such as VGG19 and VGG16 have high accuracy and F1-Score ratios. These findings suggest that deep learning techniques can be successfully used in agricultural applications to diagnose fig leaf diseases and monitor the health of fig fruit. Table 3 shows the confusion matrix and metrics.

Table 3. Confusion matrix and performance metrics of algorithms

ALGORITHMS	CONFUSION MATRIX		ACCURACY	PRECISION	SENSITIVITY	F1-SCORE
DarkNet-19	183	11	0.903	0.9433	0.8443	0.8905
	34	236				
DarkNet-53	183	11	0.9159	0.9433	0.8673	0.9037
	28	242				
EfficientNet-b0	161	33	0.8556	0.8556	0.8256	0.8278
	34	236				
GoogLeNet	178	16	0.875	0.9175	0.8091	0.8599
	42	228				
MobileNet-v2	174	20	0.875	0.8969	0.8208	0.8771
	38	232				
ResNet-50	176	18	0.9095	0.9072	0.88	0.8934
	24	246				
ShuffleNet	172	22	0.8944	0.8866	0.8643	0.8759
	27	243				
VGG-16	181	13	0.9289	0.933	0.9005	0.9165
	20	250				
VGG-19	181	13	0.9332	0.933	0.9095	0.9211
	18	252				

The main reasons for the high accuracy of the VGG-19 algorithm are the following: This model is a deep convolutional neural network with 19 layers, and this depth provides the ability to learn more features and complexity. The main reasons why the VGG-19 algorithm has a high accuracy value are: This model is a deep convolutional neural network with 19 layers, and this depth provides the ability to learn more features and complexity. Moreover, the successive convolutional layers used in VGG-19 repeatedly extract different features from the input images, enabling deeper and more complex features to be identified. Furthermore, the small size (3x3) filters used in the model help to learn more localized features and provide overall better performance. Models like VGG-19 are usually pre-trained on large datasets and learn general features from large datasets. This allows for higher accuracy with impulsive training on a new dataset. Finally, various regularization techniques can be used in VGG-19 to avoid overfitting, which increases generalizability and leads to better accuracy. Combining all these features, VGG-19 is generally highly accurate, especially on large and diverse datasets.

4. Conclusions

Overall, the study emphasizes the importance of timely detection of plant diseases as a key component in controlling the spread of plant diseases and maintaining agricultural productivity and plant health. Using artificial intelligence technologies, specifically neural network algorithms, this research aims to identify diseased fig leaves with the highest degree of accuracy. An examination of a variety of algorithms shows that they can be effective and practical in the early detection of disease, ultimately resulting in less agricultural loss as a result of the process. This study highlights the importance of using advanced AI techniques in farming to increase crop yields and better manage diseases. The results of this study show that artificial intelligence can be used to detect fig plant diseases early. By comparing different algorithms like VGG-19, ResNet50, and DarkNet-53, the research shows how AI can reduce crop losses and manage diseases. In the farming industry, these results demonstrate the value of AI models in identifying healthy and diseased fig leaves. There can be a lot of potential for future work to extend the dataset to include a broader variety of plant species and disease types, as well as exploring the integration of these AI models with real-time surveillance systems for even more timely and efficient disease management in the future.

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Research Article

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Optimizing Sodium Azide (Nan$_3$) Mutagenesis for Cumin (*Cuminum Cyminum* L.) Improvement

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HIGHLIGHTS

- Optimizing mutagen application is crucial for balancing genetic variation and seed viability.
- Sodium azide application significantly affects cumin germination parameters.
- 3 mM x 3 h sodium azide combination enhances cumin breeding mutation.
- Decrease in germination parameters dependent on the dose with increasing sodium azide concentration

Abstract

Cumin (*Cuminum cyminum*), an anciently cultivated plant of the Apiaceae family, holds significance for its aromatic seeds widely used in culinary practices globally. Despite its culinary and medicinal value, cumin faces challenges in cultivation due to diseases, pests, and weed infestations, with Alternaria leaf blight and Fusarium wilt being notable threats. Mutation breeding, a favored technique among breeders, introduces genetic variation through chemical mutagens like sodium azide, enabling the development of cumin varieties resistant to herbicides and diseases while ensuring high yields. This study aims to optimize sodium azide application as a chemical mutagen to enhance cumin breeding programs, emphasizing the importance of dosage and treatment duration in achieving desired mutation efficiency. The experimental results demonstrate significant impacts of sodium azide on germination parameters, with an optimal treatment duration of 3 hours for 3 mM sodium azide. Further research is needed to determine the effects of other variables on mutagen action, as well as M_1 plant survival and reproduction.

Keywords: Cumin; Cuminum cyminum; mutation breeding; sodium azide; germination

1. Introduction

Cumin (*Cuminum cyminum*), belonging to the Apiaceae family, is one of the oldest cultivated plants in the ancient world. Native to the eastern Mediterranean region and parts of Asia, primarily cultivated for its aromatic seeds. Its seeds, with their distinctive slightly bitter flavor, are a fundamental ingredient in the culinary traditions of numerous cultures worldwide (Lal et al. 2014; Bharti et al. 2018). Beyond its culinary role, cumin is also valued for its medicinal properties in traditional healing systems (Lodha and Mawar 2014). Ancient texts from Ayurveda and traditional Chinese medicine its use for digestive ailments, respiratory issues, and even as a stimulant (Dhandapani et al. 2002).

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The chemical composition of cumin seeds has been extensively studied, revealing a rich array of bioactive compounds such as cuminaldehyde, cuminol, and various terpenoids. These compounds contribute not only to cumins flavor but also to its potential health benefits, including antimicrobial, antioxidant, and anti-inflammatory properties. (Kumar et al. 2015; Agarwal et al. 2017; Kanani et al. 2019).

Generally, cumin is sown in arid fields to reduce fallow areas in Central Anatolia/Türkiye. There are numerous factors that also limit cumin production. Diseases, pests, and weeds in cumin cultivation areas cause significant yield losses. Cumin is highly vulnerable to Alternaria leaf blight disease, with severe epidemics occurring during rainy and mild springs, while Fusarium wilt is another pathogen that can cause yield losses of up to 45% in cumin (Didvania 2019; Budak 2020). Moreover, weed control stands out as one of the most significant challenges in cumin cultivation fields. Therefore, it is crucial to develop cumin varieties that are resistant to herbicides and diseases, while being high yielding.

Mutation breeding, favored by breeders, induces genetic variation in plants through natural processes or mutagens. Chemical mutagens induce DNA mutations in plant cells, creating genetic variation. This variation is then used through selection and crossbreeding methods to develop plants with desired traits (Oladosu et al. 2016). The most commonly used chemical mutagens include ethyl methanesulfonate (EMS), sodium azide (NaN_3), nitrosomethylurea (NMU), and hydroxylamine. Chemical mutagens cause mismatches during DNA replication or breaks in the DNA strand. These changes can alter gene function or introduce new traits (Agrawal and Kumar, 2021)

Chemical mutagens are generally applied to seeds, seedlings, or tissue cultures. The duration and concentration of mutagen application are carefully controlled based on the plant species and the desired level of mutation (Wei et al. 2013). Mutagenized plants are grown and screened for specific traits. Plants with desired characteristics are selected for further breeding programs (Serrat et. 2014). The use of chemical mutagens in plant breeding has great potential to increase agricultural production and contribute to sustainable farming practices. This method helps increase genetic diversity, enabling plants to gain resistance to environmental stresses and diseases.

The principal objective of this investigation is to enhance the utilization of sodium azide (NaN_3) as a viable chemical mutagen, serving as the initial stage in the cultivation of cumin varieties suitable for genetic resource augmentation via classical breeding methodologies. This optimization endeavor involves the precise determination of both the appropriate dosage and duration of sodium azide treatment applied to seeds.

2. Materials and Methods

2.1. Plant Material

The cumin (Cuminum cyminum) seed sample used in the study was obtained from local farmer field in Kerpic Village (39°04'02'' °N 32°34'20'' °E 1007 m above sea level) of Haymana district of Ankara province, where cumin is intensively cultivated in Center Anatolia.

2.2. Sodium Azide (NaN3) Preparation and Seed Application

First, a batch of 300 grams of cumin seeds underwent a 24-hour soaking period in cold tap water. Subsequently, they were submerged in a solution containing 1.5% NaOCl (sodium hypochlorite) for 15 minutes to ensure sterilization. Following this, the seeds were rinsed three times with distilled water to complete the sterilization process. Considering the molecular mass of sodium azide (NaN3) as 65.01 g/mol, specific amounts of NaN3 were measured for different concentrations: 0.065 g for 1 mM, 0.130 g for 2 mM, 0.195 g for 3 mM, and 0.260 g for 4 mM. Each measured quantity of NaN3 for its respective concentration was dissolved in 250 ml of distilled water, the pH was adjusted to 3, and the solution volume was brought up to 1 L. Stock solutions were prepared following this procedure. These prepared stock solutions were then applied to the cumin seeds for durations of 1, 2, 3, and 4 hours, corresponding to the designated time intervals for variation.

The selected concentrations are at an optimal level to provide effective inhibition without causing excessive damage to the cells. This range is frequently tested in many cytotoxicity studies. Sodium azide (NaN_3) has been used at these levels specifically to prevent unwanted contamination. Adjusting the pH of the solutions to 3 was done to ensure the stability of sodium azide or to achieve the optimal pH conditions for the reaction targeted by the experiment. The application duration is critical in determining the degree of mutagenic effect. In rice, mustard, and peas, it has been observed that prolonged exposure to NaN_3 increases mutation rates, but also leads to adverse outcomes such as seed mortality or failure to germinate. Therefore, application times ranging from 1 to 4 hours have been deemed appropriate to examine both the early and late effects of NaN_3 on cumin seeds (Zuo et al. 2019; Chaudhary et al. 2021; Turkoglu 2022).

After application, the seeds treated with sodium azide were placed in sealed tubes and subjected to magnetic stirring for the specified durations. Post-treatment, the sodium azide-treated seeds were removed from the tubes and air-dried at room temperature. From each treatment combination, 100 viable seeds were selected for assessment, while a control group treated with pure water was established to evaluate germination-related traits. Performance evaluation criteria included germination rate (%), germination rate coefficient, germination rate index, germination vigor index and germination time (day).

2.3. Statistical analysis

The study employed a randomized complete block design, incorporating five replicates, with one serving as the control group. To evaluate the significance of differences among the treatments, the Duncan multiple comparison test was utilized. All statistical analyses were executed using JMP Pro 16 software (SAS et al.).

3. Results and Discussion

Table 1 presents the variance analysis, mean values, and multiple comparison results for germination rate, germination rate coefficient, germination rate index, average germination time, and germination vigor index. These results are based on the different sodium azide concentrations and treatment durations applied to cumin seeds.

Table 1. Average germination parameters for cumin at different sodium azide concentrations and durations

Dose (mM)	Duration (h)	Germination rate (%)	Germination time (day)	Germination rate index	Germination rate coefficient	Germination vigor index
1	1	81,60	8,36	0,194	12,00	366,38
	2	76,00	8,61	0,180	11,62	405,40
	3	60,00	8,33	0,140	12,05	237,15
	4	59,20	8,45	0,138	10,05	162,99
Mean		**69,20 b**	**8,44 ab**	**0,163 b**	**11,43 bc**	**292,98 b**
2	1	79,20	8,56	0,188	11,68	394,76
	2	78,40	8,66	0,186	11,69	282,51
	3	51,20	9,23	0,120	11,37	285,76
	4	55,20	8,18	0,128	10,42	295,38
Mean		**66,00 bc**	**8,63 a**	**0,155 bc**	**11,29 c**	**314,60 b**
3	1	66,40	8,94	0,158	11,25	402,75
	2	52,80	7,95	0,122	12,58	278,72
	3	42,40	7,85	0,098	12,75	165,14
	4	60,00	8,39	0,140	10,52	350,23
Mean		**55,40 c**	**8,28 ab**	**0,129 c**	**11,78 b**	**299,21 b**
4	1	74,40	7,94	0,176	12,65	407,98
	2	36,00	7,96	0,086	12,59	97,62
	3	56,80	8,60	0,134	11,69	272,17
	4	49,60	8,20	0,116	10,02	197,71
Mean		**54,20 c**	**8,17 b**	**0,128 c**	**11,73 b**	**243,87 b**
Control		**87,20 a**	**8,10 b**	**0,208 a**	**12,34 a**	**471,24 a**
Mean (Time)	1	*77,76 a*	*8,38*	*0,184 a*	*11,89 ab*	*408,62 a*
	2	*66,08 b*	*8,24*	*0,156 b*	*12,12 a*	*307,10 b*
	3	*62,24 b*	*8,42*	*0,140 b*	*11,96 ab*	*286,29 b*
	4	*59,52 b*	*8,26*	*0,146 b*	*10,25 b*	*295,51 b*
General Mean		**70.70**	**8.14**	**0.170**	**12.04**	**357.56**
ANOVA		*p > F*				
	df					
Dose (D)	4	**	**	**	*	**
Time (T)	3	**	ns ‡	**	**	**
D x T	12	**	**	**	**	**

* P < 0.05; ** P < 0.01; ‡ ns, not significant. ð Means within a column not sharing a lowercased letter differ significantly at the P < 0.05 levels

It was determined that the dose and time application significantly affected all germination parameters. Also, duration x time interaction has been statistically significant in all parameters except germination time. As seen from Table 1, the lowest germination rate (54,20%) was obtained from 4 mM sodium azide doses. With each decreasing dose, the germination rate increased, and it was observed highest in the control group (87,20%). In other words, it means that as the concentration of sodium azide increased, the germination rate decreased, and the control group had a notably higher germination rate than the groups treated with sodium azide. As a result of the combination of treatments, the highest germination rate (81.60%) was achieved with the application of 1 mM x 1 hours. The lowest germination rate index (36,00%) was obtained by applying 4 mM x 2 hours (Figure 1). As shown in Table 1, the highest germination rate index (0.208) was observed in the control group. Following this, the germination rate index for the sodium azide doses were 1 mM (0.163), 2 mM (0.155), 3 mM (0.129), and 4 mM (0.128), respectively. The germination rate index decreased as the concentration of sodium azide increased, with the control group exhibiting a significantly higher germination rate compared to the sodium azide treatments.

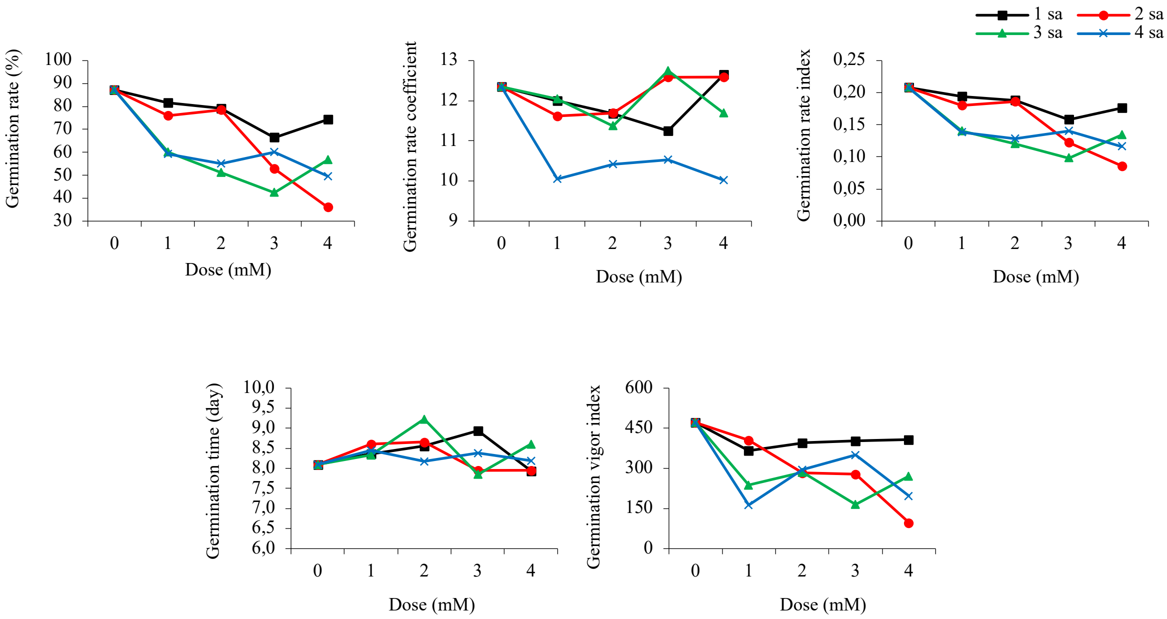

Figure 1. The effects of different sodium azide concentrations and durations on germination parameters

The average germination time varied depending on the sodium azide concentration, ranging from 8.10 to 8.63 days. The control group germinated the quickest, while the 2 mM sodium azide treatment resulted in the slowest germination. For the other sodium azide concentrations, the average germination times were 8.44 days for 1 mM, 8.28 days for 3 mM, and 8.17 days for 4 mM. Across all treatments, the overall average germination time was 8.14 days. Additionally, the interaction between time and dose was found to be insignificant for this parameter.

The control group exhibited the highest germination rate coefficient with an average value of 12.34. For the 1 mM sodium azide treatment, the average germination rate coefficient was 11.43, with values ranging from 10.05 to 12.05 across the four time points. The 2 mM sodium azide treatment showed an average germination rate coefficient of 11.29, with individual time point values between 10.42 and 11.69. The 3 mM sodium azide treatment had an average germination rate coefficient of 11.78, with the lowest value at 10.52 and the highest at 12.75. For the 4 mM sodium azide treatment, the average germination rate coefficient was 11.73, with values spanning from 10.02 to 12.65. Across all sodium azide treatments, the germination rate coefficients were lower than that of the control group.

The germination vigor index, a crucial indicator of seed viability and potential for successful germination, was meticulously assessed across various concentrations of sodium azide, along with a control group. Intriguingly, the control group displayed the most robust vigor index, with a mean value of 471.24, underscoring its superior seed quality and viability. However, as the concentration of sodium azide escalated, a noticeable decline in vigor index became evident. For instance, seeds treated with 1 mM sodium azide exhibited a mean vigor index of 292.98, while those subjected to 4 mM sodium azide displayed a notably lower mean vigor index of 243.87. This dose-dependent reduction in vigor index implies a detrimental impact of sodium azide on seed viability and germination potential.

It is stressed that within the domain of plant breeding, there exist numerous alternative methodologies, which should ideally complement each other. Nonetheless, mutation breeding has emerged as a notably efficacious approach compared to its counterparts, chiefly because the outcomes of mutagenesis have often been swiftly integrated as new varieties. This method endows breeders with two pivotal advantages: firstly, it furnishes a pool of unselected genetic diversity, and secondly, it facilitates the augmentation of genetic variability, thereby facilitating selection and cross-breeding endeavors. Cumin emerges as an attractive candidate for mutation breeding owing to its diminutive floral structures and limited genetic variation available for conventional breeding efforts. This strategic application of mutagenesis has historically served as a viable avenue for enhancing quantitative traits, leveraging the innate potential for genetic enhancement in plant species. In the study conducted by Yadav and Krishna (2013) on cumin plants, three different doses of sodium azide (0.2, 0.4, and 0.6 mM) were applied to seeds for 6 hours to investigate their mutagenic effects. They observed a decrease in germination with increasing doses of sodium azide. The doses they used were relatively low compared to our study, while the duration was high. But, applying a higher dose is important to increase genetic damage and induce more variations. Emrani et al. (2011) reported that increasing doses of sodium azide reduced germination percentages and germination rate index in rapeseed plants, and the combination of 6 mM for 8 h reduced germination by 50% compared to the control group. The same result was reported by Ingle et al. (2018) in fenugreek, Prabha et al. (2010) in black cumin, and Raina et al. (2022) in cowpea, as well as by Srivastava et al. (2010) in wheat. Sodium azide can induce point mutations and disrupts the developmental, physiological, and metabolic processes of the treated plant species (Mensah and Obadoni 2007). The decrease in germination parameters observed following the application of sodium azide may be linked to point mutations or other forms of genetic damage (Vinithashri et al. 2020). In addition, in the study conducted by Patel et al. (2023) on cumin plants, it was found that high doses of gamma rays and EMS created a significant difference in the plant population in the M_1 generation, and these treatments increased the mutation frequency in the M_2 generation.

4. Conclusions

The significant effects of mutagen doses and application periods on germination rate, germination rate coefficient, germination rate index, germination vigor index, and germination time in cumin were observed. The study aimed to establish a balance between mutation efficiency and seed viability. Longer durations or higher concentrations can induce more mutations, but they may significantly reduce seed viability. Therefore, the selected duration and concentration represent a compromise that maximizes mutation efficiency while ensuring an acceptable level of seed viability. Hence, optimum treatment conditions were determined as 3 hours for 3 mM sodium azide combination. This study represents a step towards exploring the most suitable treatment conditions to enhance mutation efficiency in cumin breeding programs and genetic studies. Further research is needed to determine the effects of other variables on mutagen action, as well as M_1 plant survival and reproduction.

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Research Article

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Silage Yield and Quality of Forage Peas and Hungarian Vetch and Triticale Binary Mixtures

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HIGHLIGHTS

- The importance of mixed cropping and silage in forage crop production is understood in Turkey as well as all over the world.
- The study integrated the mixed cropping system, which provides better quality feed in silage production and more effective use of unit area.
- In this context, the silage quality of legume + triticale planting rates was determined and the 80:20 T/HV process came to the fore.

Abstract

This study was conducted to determine silage quality in binary mixtures of forage pea (*Pisum sativum* ssp. *arvense* L. "FP") and Hungarian vetch (*Vicia pannonica* C. "HV") and triticale (X *triticosecale* Wittmack. "T") in 2021-2022 vegetation period. Hungarian vetch, forage pea, and triticale seeds were sown in 6 different mixture ratios (legume/triticale; 100%/0, 80/20%, 60/40%, 40/60%, 20/80%). The experiment was established according to a randomized blocks experimental design with 3 replications. In the study, dry matter content, pH, flieg score, quality class, crude protein, ADF, NDF, Ca, K, Mg, P, lactic acid and acetic acid contents were analyzed for silage yield and quality. The dry matter of silages was between 23.83 and 36.49%, while the pH was between 4.57 and 5.18. The highest crude protein was determined in pure forage peas (22%) and it was determined that it increased in parallel with the increase in the legume ratio in the mixture. Mineral contents were found to be high in sole and intense legume silages, similar to crude protein. In terms of silage quality in the examined parameters, mixed sowing gave better results than sole sowing. As a result of the study, 80:20 T/HV mixture ratio sowing is recommended for Yozgat and regions with similar ecology in terms of silage yield and quality.

Keywords: Hungarian vetch; Triticale; Forage pea; Silage quality

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1. Introduction

High forage costs in Turkey are a major problem for animal production enterprises. The insufficient level of roughage produced is the main reason of forage cost increase significantly (Ceyhan and Karadaş 2022). Livestock production in Turkey depends on a large amount of pastures. Due to excessive and prolonged grazing of pastures, these areas, which are a source of cheap forage, are insufficient for animal production. Therefore, to meet the need for roughage in Turkey and increase animal production, it can be achieved by increasing the production of forage crops.

The forage crops have characteristics such as quality forage source for animals, can leave fertile soil for the plant, uses in the crop rotation, and can conserve water and soil (Ceyhan et al. 2012). Also, the essential energy for animals to have a balanced and adequate nutrition should be provided from forage crops. For this purpose, it is appropriate to plant legumes mixed with grasses. In Turkey, silage obtained from intercropping of leguminous with grasses, which has become increasingly widespread in recent years, has become an important source of roughage. Silage is deliciously consumed by animals because of its high water content and fresh.

Forage peas and vetch, which have high protein content, together with cereals with high starch content, provide an easy-to-digest and high quality feed for animals (Elçi 1975). By intercropping legumes with cereals, diseases such as tympani and grass tetenosis that occur in animals can be reduced. Silage, which is one of the most important quality forages, is widely used in many countries around the world due to its ability to reduce losses in forages due to its high water content. With silage production, animals can access fresh quality roughage throughout the year. Legume silages have a higher nutritional value for dairy cows compared to cereals. However, due to their high protein content and high buffering capacity, it is more difficult to make silage than cereal (Keleş et al. 2013). Because the low protein content of cereals negatively affects the quality, especially in silage production, while the lactic acid and pH amounts are not at the desired level with pure legumes, so the increase in lactic acid, protein and pH amounts when cereals are sown together or mixed with legumes is an essential factor.

This proposed study was planned to determine the silage yield and quality in the intercropping of Hungarian vetch (*Viciapannonica* Crantz.) and forage pea (*Pisum sativum ssp.arvense* L.) and triticale (*Xtriticosecale* Wittmack.) at different rates.

2. Materials and Methods

Hungarian vetch (HV; *Vicia pannonica* Crantz.) Altınova 2002, forage pea Özkaynak (FP; *Pisum sativum* ssp. *arvense* L.) and triticale (T; X *triticosecale* Wittmack.) Karma 2000 seeds were used as material in the study.

Soil samples taken from 3 different parts of the land and 30 cm depth were analyzed by Yozgat Chamber of Agriculture. When the soil properties of the research site are analyzed, it is seen that it has a soil structure with clay loam, slightly salty, medium calcareous, medium organic matter content and high phosphorus content.

As seen in Table 1, the long-term rainfall average for the growing period in which the research was carried out in Yozgat conditions was 544.6 mm. This data was realized as 562.4 mm in the year the study started, and 17.8 mm more rainfall was realized in the 2021-2022 growing period compared to the long-term average.

The average temperature in Yozgat for many years (1929-2021) was 7.1°C. The average temperature in the 2021-2022 growing period in which the study was conducted was 6.9°C. This value is lower than the long-term average. Relative humidity in Yozgat is 68.7% according to the long-term average and 67.5% in the 2021-2022 growing period.

Table 1. The climate data for 2021-2022, the year of the study, and for many years (1929-2021) are presented in Table 1.

	Total Precipitation(mm)		Average Temperature(°C)		Average Relative Humidity (%)	
Months	**2021-2022**	**Long Years**	**2021-2022**	**Long Years**	**2021-2022**	**Long Years**
November	65.4	53.7	6.6	5.1	72.8	71.9
December	77.1	75.9	1.9	0.6	74.7	77.7
January	121.1	67.9	10.1	-1.7	62.9	77.6
February	48.8	59.8	-2.4	-0.6	76.6	75.3
Mart	83.3	68.2	0.2	3.0	77.1	70.9
April	16.4	58.3	-1.5	8.5	73.9	64.9
May	50.2	66.3	11.6	13.1	47.4	63.5
June	98.9	67.4	17.5	16.7	64.3	60.7
July	1.2	27.1	18.5	19.6	57.9	56.0
Total/Mean	**562.4**	**544.6**	**6.9**	**7.1**	**67.5**	**68.7**

Data of the General Directorate of Meteorology for Yozgat province for many years and the year of the research (Anonymous, 2023)

The experiment was conducted at the YOBU Research and Application Center during the 2021/2022 vegetation period. Sowing was carried out in November with four different ratios for each legume (80HV-FP+20%T, 60%HV-FP+40%T, 40%HV-FP+60%T, 20%HV-FP+80%T) and lean. The experiment was established according to the Randomized Block design with three replications. In the experiment, the plots were 6 meters long with a row spacing of 20 cm, 6 rows were sown by hand, and one row was sown as wheat and one row as legume. The amount of seed per decare was adjusted as 12 kg for Hungarian vetch and forage pea and 22 kg for triticale. The amount of seed to be included in the mixtures was calculated based on the amount used in lean sowing and the mixture ratio (Önal and Eğritaş 2017). The experiment was irrigated 1 time.

Preparation and examination of silages

Harvesting time for silage was based on the developmental stage of triticale in the mixtures, triticale was harvested at the dough stage and legumes were harvested when the lower pods started to form. Harvested samples for silage were chopped into 2 cm pieces according to the mixture ratios (Alaca and Özaslan Parlak, 2017) and filled into 1.0 kg plastic drums in 3 replicates. The silage samples were left for fermentation airless and at 25±2 °C. The fermented silages were opened after 45 days. Silage sampling was done by removing the top 3-4 cm of the bins and the following parameters were analyzed.

The physical analyses determined after opening the silage samples are given in Table 2. For pH, 100 ml of distilled water was added to 20 g of samples taken from the silages and mixed homogeneously with the help of a blender and filtered through filter paper and filtered into 50ml sieve tubes (Başaran et al. 2018). The pH of the obtained silage water was determined with a HANNA Edge digital pH meter. Flieg score which one of the common methods used to determine silage quality is the relationship between dry matter content and pH of the silage.

FP=[220+(2XsilageCMRatio-15)]-40XsilagePH (Anonymous, 1987).

The 100 g from the fermented silage samples were dried in an oven at 1050 C until reached constant weight and dry matter content (%) was determined by the weighing. For chemical analysis, 100 g of silage sample was dried at 60 0 C and ground 1mm diameter. Afterwards, the total N values of these samples were determined by the Kjehldahly method and crude protein ratios were calculated by multiplying these values by a coefficient of 6.25 (Basaran et al. 2018). ADF, NDF and mineral matter contents (Ca, K, Mg and P) (%) were determined using IC-0904-FE calibration program on FossNIRSystemsModel6500WinISIIIv1.5

instrument. Lactic, acetic and butyric acid analyses in silage samples whose pH was determined were carried out by HPLC (high performance liquid chromatography) device at YOBU, Science and Technology Application and Research Center. Butyric acid was not found in silage samples.

Table 2. Physical evaluation key of silages developed by the German Agricultural Organization (DLG).

1. Odor	**Score**
No buttery acidic odor, slightly sour, fruity and aromatic odor	14
Small amounts of butter acid, strong odor of heat and mild frying	8
Moderate odor of butter-oil acid, strong smell of fumes	4
Strong odor of butter-acid or ammonia, very light odor	2
Strong smell of rot, ammonia and mold	0
2.Appearance (Structure)	
Leaves and petiole structure intact	4
The structure of the leaves is slightly deformed	2
Leaves and leaves are decomposed, moldy and dirty	1
Leaves and stalks rotten	0
3.Color	
Retains its color when siloed (brown in withered silage)	2
Color slightly changed (yellow to brown)	1
Color completely changed (musty-green)	0

Statistical analyzes

The results obtained were subjected to analysis using SPSS 20.0 statistical package program according to randomized blocks experiment design. The averages of the treatments between which differences were determined were evaluated according to the Duncan multiple comparison test and grouped.

3. Result and Discussion

The averages of the physical and chemical parameters of the silages prepared from different mixture ratios of Hungarian vetch, forage pea and triticale and their Duncan grouping are shown in Table 3. The difference between the mean values of all the characteristics was found to be statistically very significant ($p<0.01$). Table 3 shows that the silage dry matter ratio was between 23.83 and 36.49, while the pH was between 4.57 and 5.18. The highest silage dry matter ratio was 100% T (36.49) and the lowest silage dry matter ratio (23.83) was 100% HV. The highest silage pH value was obtained from 100% triticale and the lowest value was obtained from 60:40 T/HV (4.57). As the legume (forage pea and Hungarian vetch) ratios decreased in the mixtures, an increase in dry matter ratio was observed. One of the most important factors determining the quality of silage is the dry matter content of silage. It has been proved by most studies that the increase or decrease in the dry matter content increases the quality of forage (Mut et al. 2020). The highest (89.24) fleig score calculated in silage samples was observed in 80:20T/HV mixture and the lowest (52.94) was observed in 100% HV. Also, while 40:60T/HV, 60:40T/HV and 80:20T/HV were in the same group, 20:80T/HV was in a different group. The highest quality class was 80:20T/HV (89.24) and 60:40T/HV (82.34) and the quality class were 'very good'.

In previous studies, Akgül (2010) reported that the dry matter content of green forage to be silage should be (25-30%). Gümüştaş and Turan (2022) found the most high dry matter content was in 75% forage peas + 25% cereal silage. Yavuz (2022) found that the highest dry matter rate (32.08%) and pH (4.65) were determined from pure barley. In similar studies, Ashbell (1997) found the highest dry matter content (38%), Arslan and Çakmakçı (2011) found the highest dry matter content (31.38%) and Dumlu et al. found the highest (31.36%). Abeidy (2022) reported that the pH values of oat + legume silages were varied between to 4.72-6.56. Gomes et al. (2019) investigated the addition of heterofermentative lactic acid bacteria in lightly wilted or directly harvested oat silage and reported that pH values were (3.90-4.61), (4.05- 4.59), respectively. Romero et al, (2017) pH values of silages prepared in polyethylene bags and plastic drums in control and inoculant groups were (6.10-6.04), (6.13-6.16), respectively. Erbil (2012) investigated the effects of heterofermentative and/or homofermentative lactic acid bacteria in Hungarian vetch + wheat grain mixture silages, pH values were (4.59, 4.42, 4.40 and 4.37) on the 2nd, 4th, 8th and 45th days, respectively; Marković et al, (2018) reported that the pH values were between (4.13-4.89), (4.17-4.61), respectively (4.13-4.89) in their study investigating the addition of bacterial inoculant to mixtures of common vetch and oat at different ratios. Polat (2022) reported that the highest silage dry matter rate was determined from pure oat (31.49), the highest silage pH value was between 4.57 and 5.52 and the highest pH value was determined from pure forage pea (5.52). Yavuz (2022) reported in his study that the highest values in flieg score and quality criteria were obtained from pure barley in both (16-90) and were classified as very good. Polat (2022) reported that the average values of flieg score varied between 30 and 80 and the highest value was obtained from oat + faba bean (75:25) and was classified as good. Mut et al., (2020) concluded that when the flieg scores and crude protein ratios of the silages were evaluated together, it was concluded that the quality of the silages made with alfalfa and forage turnip in all the ratios considered and with oat at a ratio of 75+25% were higher. Karadeniz et al. (2020) obtained the highest flieg score from triticale silage in their study.

Table 3. Dry matter content (DM;%), pH, flieg score and quality class in silages of triticale with legumes silages mixtures.

Treatments	DM**	pH**	Flieg score**	Quality Class
Triticale(T)	36.49 a	5.18 a	72.02 c	Good
Hungarian vetch (HV)	23.83 g	4.98 b	52.94 f	Middle
Forage pea (FP)	22.75 g	4.78 c	59.90 e	Middle
20:80T/HV	27.50 e	4.63 e	74.86 bc	Good
40:60T/ HV	31.10 cd	4.72 d	77.64 b	Good
60:40T/ HV	31.36 cd	4.57 f	82.34 ab	Very good
80:20T/ HV	32.66 b	4.58 f	89.24 a	Very good
20:80T/FP	25.62 f	4.76 c	65.46 d	Good
40:60T/ FP	27.76 e	4.65 e	77.16 b	Good
60:40T/ FP	30.59 d	4.69 d	79.76 b	Good
80:20T/ FP	32.14 bc	4.71 d	79.68 b	Good
Mean	29.25	4.75	73.72	Good

**:$p<0.01$; there is no difference between means indicated with the same letter ($p<0.05$).

The highest (22.82%) crude protein in silage samples was in 100% FP and the lowest (6.34%) crude protein content was in 100% T. As the legumes ratios in the mixtures decreased, the crude protein ratios also decreased linearly as expected. Also, the average CP of the samples was (13.89%). The highest ADF and NDF contents were in sole triticale (40.16%) and (69.0%), respectively. The lowest ADF and NDF contents were (22.82%) and (39.8%) in sole forage pea (Table 4).

Similarly, Yavuz (2022) and Karadeniz et al. (2020) determined that legume silages had higher protein content. However, Görü and Seydoşoğlu (2021) reported that the highest CP ratio was found to be 75% in the mixture of common vetch. Kaymak et al., (2021) reported that the highest CP was obtained from a mixture of 80%B+20%WW (15.58%) and 80%B+20%WW (15.58%) mix silages. In their study, Mut et al. (2020) found that the quality of the silages made with alfalfa and forage turnip and oats at a ratio of 75+25% were higher in terms of their crude protein ratios.

Table 4. Crude protein content (CP; %), ADF (%) and NDF (%) contents in silages of triticale with legumes silages mixtures.

Treatments	CP**	ADF**	NDF**
Triticale(T)	6.34 f	40.16 a	69.0 a
Hungarian vetch (HV)	18.81b	33.46 cd	46.8 d
Forage pea (FP)	22.82 a	22.82 f	39.8 e
20:80T/HV	14.28 c	35.64 bc	55.8 c
40:60T/ HV	11.41e	39.07 a	61.7 b
60:40T/ HV	10.85 e	37.16 ab	62.1 b
80:20T/ HV	11.28 e	36.93 ab	63.4 b
20:80T/FP	17.78 b	29.82 e	51.0 d
40:60T/ FP	14.80 c	30.73 de	55.8 c
60:40T/ FP	12.72 d	32.61 cde	58.6 bc
80:20T/ FP	11.72 e	33.35 cd	59.7 bc
Mean	13.89	33.80	56.71

**:p<0.01; there is no difference between means indicated with the same letter (p<0.05).

Kaymak et al. (2021) reported that the ADF content of silages varied between (25.87%-30.24%), Karadeniz et al., (2020) obtained the highest ADF rate from 100% damson silage. In Paydaş's (2018) study, the highest ADF rate was found in vetch silage with (44.46%) in May harvest period and the lowest ADF value was found in vetch silage with (31.76%) in May harvest period. Jung et al. (2015) found ADF values between (30.4% and 34.8%) by using a mixture of vetch and barley in their study on silage yield. Balabanlı et al, (2010) in their experiment on the quality of silages obtained from a mixture of common vetch and oat, the lowest NDF (50.11%) and ADF (31.92%) ratios were found in the mixture of common vetch + oat. Jung et al. (2015), found NDF ratios between 50.2% and 55% in their silage research with barley and vetch mixture.

Table 5. Mineral matter contents (%) in silages of triticale with legumes silages mixtures.

Treatments	Ca**	K**	Mg**	P**
Triticale(T)	0.33e	3.47d	0.18e	0.32e
Hungarian vetch (HV)	1.55a	4.56a	0.35a	0.34d
Forage pea (FP)	1.45a	3.58cd	0.36a	0.39a
20:80T/HV	1.20b	3.99b	0.32b	0.32e
40:60T/ HV	0.90cd	3.72c	0.28d	0.29f
60:40T/ HV	0.85d	3.53cd	0.29cd	0.31e
80:20T/ HV	0.79d	3.49d	0.28d	0.31e
20:80T/FP	1.07b	3.57cd	0.31bc	0.36bc
40:60T/ FP	1.04bc	3.50d	0.32b	0.36b
60:40T/ FP	0.86d	3.50d	0.27d	0.35cd
80:20T/ FP	0.86d	3.54cd	0.28d	0.36bcd
Mean	0.99	3.68	0.29	0.34

**:p<0.01; there is no difference between means indicated with the same letter (p<0.05).

Generally, Ca, K, Mg and P contents were found to be higher in legume silages than in mixtures (1.55, 4.56, 0.36 and 0.39%, respectively). Table 5 shows that the addition of legumes to silages provides significant increases in mineral content. Similar a study, Turan (2018) found that the average Ca, P, Mg, and K ratios of the silages obtained from different blends of Hungarian vetch and barley (1.31, 0.56, 0.20 and 3.01%, respectively). Kidambi et al. (1989) reported that the content of (0.31%) Ca, (0.65%) K, (0.1%) Mg and (0.21%)

P in the ration for regular feeding of animals. When the minerals in the silages obtained are compared with the findings of the researchers, it can be said that they are above the amount that should be present in the animal feed and this will not pose any nutritional problem for the minerals mentioned.

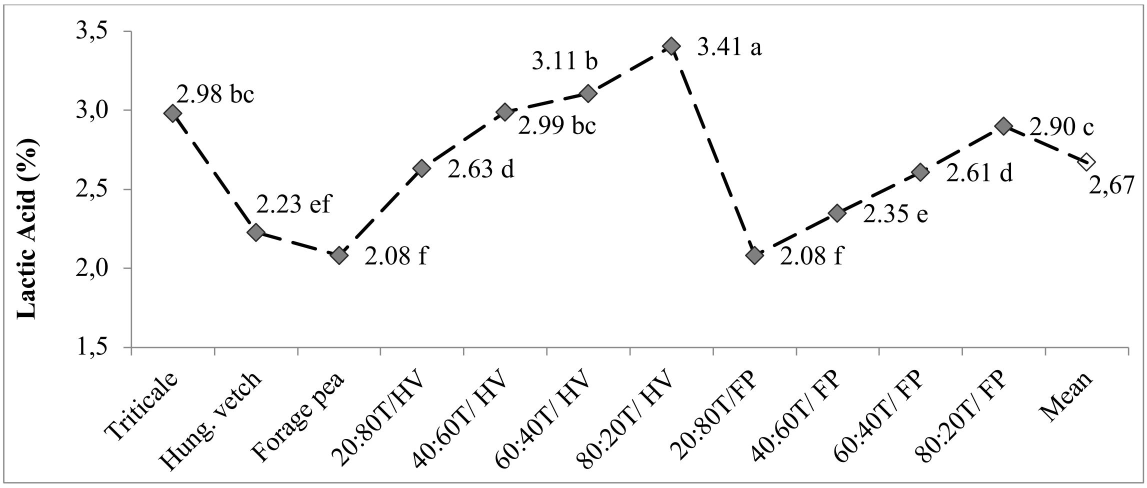

Figure 1. Lactic acid content in silages of triticale with legumes silages mixtures

The LA contents of the species in the study are given in Figure 1 and the results of the analysis were found to be very significant (p<0.01).The highest LA (3.41%) was in 80:20T/HV while the lowest LA (2.08%) was in 80:20T/HV and forage pea. In addition, the proportion of legumes in the mixtures (HV and FP) generally decreased while the LA content increased inversely. In other studies, Yıldırım (2020) found that the lactic acid rate in legumes varied between (1.80-2.03%), with the highest lactic acid rate (2.03%) in forage pea. However, in the study conducted by Paydaş (2018), the highest lactic acid value (29.08 g/kg) was obtained in barley silage with the highest KM ratio. In another study, Jung et al. (2015) reported that the highest lactic acid rate (3.27 g/kg) was obtained from barley and vetch mixture silage. Kavut et al. (2012) and Aykan and Saruhan (2018) obtained in the highest LA from sole grass silages. Açıkbaş (2022) reported that the highest LA ratio (1.56%) in branched millet silages was found in Cave in Rock variety.

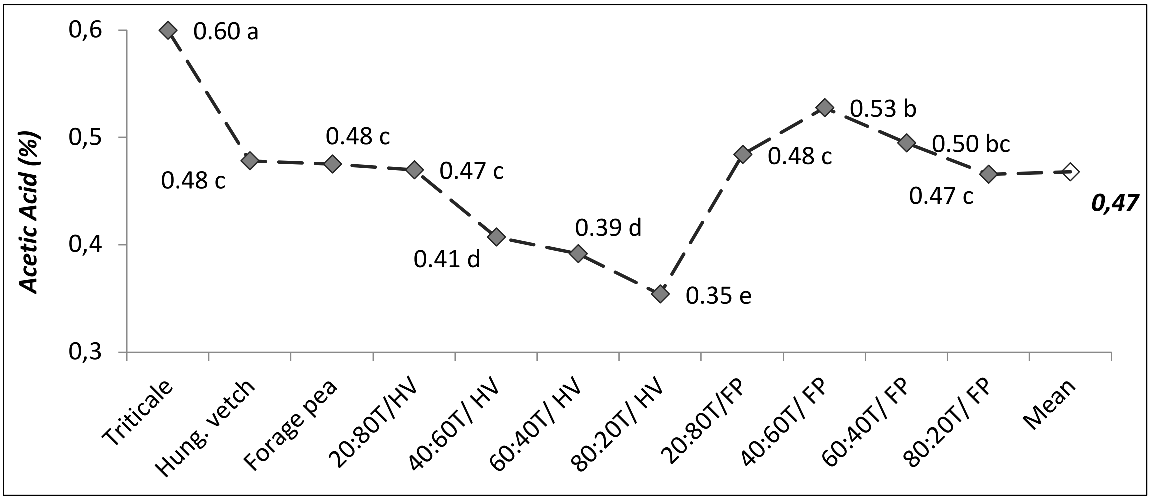

Figure 2. Acetic acid content in silages of triticale with legumes silages mixtures

The acetic acid (AA) contents of the treatments under investigation are illustrated in Figure 2, revealing highly significant results ($p < 0.01$). Among the different compositions, pure triticale exhibited the highest AA content at 0.60%, while the 80:20T/HV mixture had the lowest acetic acid content at 0.35%, resulting in an average AA content of 0.47% across all species. Notably, the 80:20T/HV mixture (0.47%) clustered with the 20:80T/HV (0.48%) mixture, demonstrating similar AA levels. Additionally, the linear increase in legume ratios in the mixtures (HV to FP) was associated with a general rise in AA content.

In a study by Jung et al. (2015) involving a barley and vetch mixture, the highest acetic acid content was observed in the 70% barley-30% vetch combination (0.20 g/kg), whereas the lowest acetic acid content (0.11%) was found in the barley-vetch silage. Kavut et al. (2012), investigating silage yield and characteristics of various triticale varieties, reported silage acetic acid ratios ranging from 0.40% to 0.60%.

Quality silage parameters were considered in accordance with established standards. Panyasak and Tumwasorn (2013) suggested that 25-40% of dry matter is essential for quality silage. Alçiçek and Özkan (1997) also highlighted the importance of lactic acid exceeding 2% and acetic acid being below 0.8%. Otherwise, deviations from these values can lead to deterioration, as the growth of Clostridium spp. anaerobic bacteria may occur, causing the breakdown of sucrose and protein into butyric acid and ammonium. This can elevate the pH up to 5.0, beyond the recommended range of (3.7 to 4.8) Filya (2002), compromising silage quality. Considering the nutritional needs outlined by Kidambi et al. (1993) and Tekeli and Ateş (2005), where forage should contain a minimum of 0.8% potassium, 0.21% phosphorus, 0.3% calcium, and 0.1% magnesium to provide a balanced diet for animals, it was determined that all mixed silages in our study met these quality criteria. Consequently, there was no indication of deterioration, and these silages are deemed suitable for healthy animal consumption.

4. Conclusion

When the quality parameters of the silage samples were evaluated together, it was determined that pure legumes/triticale silages were inadequate compared to the mixtures, and Hungarian vetch and triticale mixtures gave better results than forage peas. In addition, it was concluded that 80:20T/HV mixture produced better quality silage among the mixtures grown for silage in Yozgat conditions, especially in terms of LA and AA content when all examined parameters are evaluated together.

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Sunflower Crop Yield Prediction Using Machine Learning Methods

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HIGHLIGHTS

- Sunflower plant is affected by many factors
- Providing a timely and robust prediction for sunflower crop yields
- Increasing the effectiveness of the AI methods using Halving Grid Search method

Abstract

Sunflower, one of the most important crops, is produced in many countries to meet especially for edible oil demand. Since the sunflower plant is affected by many factors, such as the amount of rain and air temperature, the yield changes from year to year, which has adverse effects on the balance between demand and supply. Because of the product produced in many countries is not enough; it has to be imported. Turkey is one of the world's leading sunflower importers. The yield must be accurately estimated for the imported quantity to be correct. Importing in large quantities causes inventories, while small quantities cause the sunflower oil demand to not be met. It is used methods such as the direct method, simulation, and remote sensing to estimate sunflower yield. However, these methods have some shortcomings. In this article, machine learning methods, such as decision tree (DT), support vector machine (SVM) and random forest (RF), are used for production prediction. In order to increase the effectiveness of the methods, the values of the hyperparameters are determined by Halving Grid Search (HGS) method that is tuning method. The methods were implemented in Edirne, which is among the province with the highest sunflower yield in Turkey. The results were evaluated with ANOVA method and performance evaluation criteria, MAE, MAPE, RMSE, and R^2. The R^2 values obtained for the test data were determined as 0.92, 0.68 and 0.80 for the DT, SVM and RF methods, respectively. In addition, the number of combinations and execution times were compared using the grid search method and the HGS method for the DT method that gave the best results. While 644204 combinations were solved in 4608 seconds with grid search, 5324 combinations were solved in 23 seconds with HGS. Thus, DT method, providing the prediction with the lowest error, is determined a suitable method for sunflower yield prediction and then accurate buying decision making.

Keywords: Sunflower production; Machine learning; Decision tree; Halving grid search method.

1. Introduction

Agriculture plays an important role in the economic development of countries by increasing food security and social well-being and limiting the impact of climate change (Mok et al. 2014; Byerlee et al. 2009; Palatnik

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and Roson 2012). Accurate and timely crop yield prediction is extremely valuable for agricultural resource managers and crop producers to ensure food security and sustainability encountered in agricultural production and planning import and export. Food security is one of the critical issues facing many countries. Major fluctuations in crop yield from year to year have serious adverse effects on the balance between supply and demand (Abbott et al. 2011). If the precision of crop yield estimation is improved, the socioeconomic impact of crop loss can be minimized. However, crop yield prediction is extremely challenging due to numerous complex factors (Khaki and Wang, 2019).

As a crop type, the sunflower plant (*Helianthus annuus* L.) is grown in many countries to contribute to the economy. Sunflower is one of the most important annual crops in the world, and it is grown for edible oil (Putt 1977; Ceyhan et al. 2008). It has a high oil content (%36–%55) (Önder et al. 2001; Narin and Abdikan 2022). Sunflower oil ranks first in terms of edible oil quality. In addition, sunflower oil is one of the oils with high nutritional value. Although the sunflower plant is mostly planted to obtain oil, is also used as a snack, bird seed, industrial plant, and ornamental plant.

According to 2018 data, 46% of vegetable oil production in Turkey is met by sunflowers (USDA 2020). In sunflower cultivation, Turkey ranks 6th in world production and has a share of 4.12%. It is expected that the production amount will reach 2,6 million tons in 2023 (URL_1, 2023). Global sunflower production is estimated to be 50.7 million tons in the marketing year of 2022–23, with a decrease of 11.6% compared to the previous year. In Turkey, an increase in production is expected, but it is expected that this increase will not be able to cover the total losses. However, the need for edible oil in Turkey increases in parallel with the per capita consumption and population growth, the amount of production cannot meet the entire demand and efficient increases from year to year and has exceeds 500 thousand tons.

Because the increasingly significant oil deficit is met through seed and crude oil imports, making the country dependent on foreign sources for raw materials. Turkey's average proficiency level in the last 20 years has been 57 percent. During this period, 43% of the need was met by imports. Accordingly, total sunflower imports were 3.3 million tons in the 2019/20 season, while exports were only 1.94 million tons (Republic of Turkey Ministry of Agriculture and Forestry 2022). Turkey is one of the larger sunflower importer countries in the world. But, epidemics, natural disasters, and wars in the world and in importing countries cause major disruptions in supply. The yield must be accurately estimated for the imported quantity to be correct.

For sunflower yield prediction, simple methods such as farmers' long-term experience for specific fields, the average of several previous yields, or the last obtained yield can be used. However, these methods have some shortcomings. Nevertheless, crop yield varies from one year to another, with large deviations. The direct method, crop simulation, remote sensing and statistical methods are commonly known crop yield estimation methods. The direct method is based on ground measurements. Although these methods give reliable predictive results, they are not cost and time efficient, and therefore it is very difficult to apply the on large areas (Burke and Lobell 2017). Crop growth simulation models are also used for crop yield estimation, which includes ecophysiological processes to simulate crop growth, development, and yields according to soil characteristics, agricultural practices, and meteorological data (Leroux et al. 2019). In the statistical method, it is assumed knowing how input variables are related to the output. It is wrongly determined the relationship between input and output by user, it may result in inaccurate prediction model. Remote sensing (RS) technology is a method for better productivity and yield estimation because it allows for the evaluation of the widest fields and gives functional preliminary information about the growing crops (Narin and Abdikan 2022). However, most agricultural fields in developing countries are managed by farmers with small production areas. It is also true that such predictions are difficult to achieve in regions that lack extensive observational records.

Recently, machine learning (ML) methods have been used for yield prediction. In these methods, since the complex relationships of the variables can be defined by the learning model, higher accuracy prediction can be made compared to traditional methods (Kayad et al. 2019). The methods can be successfully used to identify factors that increase crop production under different environmental conditions and also to model and predict future yields (Mourtzinis et al. 2021). SVM, RF or ANN are some of the most popular ML methods used for the prediction of crop yield (Debaeke et al. 2023).

There are few studies using ML methods predicting yield in the literature. Gonzalez-Sanches et al. (2014) compared the predictive accuracy of ML methods such as multilayer neural networks, support vector regression, k-nearest neighbor, and linear regression techniques for crop yield prediction. Călin et al. (2022) aimed to predict sunflower and corn yields by using ML method, based on the plating date and region, with limited available data. Amankulova et al. (2023) used three ML-based regression analysis techniques, multiple linear regression (MLR), random forest regression (RFR), SVM, to predict crop yield. In the methods, accepted values were extracted from remote sensing (RS)-derived vegetation indices (VIs) were as explanatory variables while the predicted crop yield was the response variable.

In this article, it is aimed to structured ML models predicting sunflower yield. But the biggest disadvantage of machine learning methods is determining the hyperparameter values that give the best results. Inappropriate or wrong hyperparameter values used can reduce the prediction performance of the method. In this study the HGS method, is hyperparameter tuning method, was used to determine to reduce all possible combinations of hyperparameters in training phase. Thus, the model is trained on a small subset of data rather than the entire training data.

In the application, 5 input variables were determined as cultivated area, average humidity, average temperature, total sunshine time, and average precipitation, and production amount (ton) was determined as the output variable. 58 years of data for all variables were collected, and a 6x58 dataset was created. The created dataset was divided into 6x41 training dataset and 6x17 testing dataset.

Developed models of SVR, RF and DT methods applied to Edirne province. The prediction accuracy of ML methods was evaluated with ANOVA method and performance criteria such as mean absolute error (MAE), mean absolute percentage error (MAPE), root mean squared error (RMSE), and determination coefficient (R^2).

The following sections of this paper are organized as follows. Section 2 elaborates the methods and materials used in this study. In section 3, model's implementation is described. Results are presented in section 4. Section 5 gives a discussion on the results obtained.

2. Materials and Methods

2.1. Materials

Data for the years 1960–2021 were used as the basis. Sunflower cultivation area size and yield amount data were obtained from the Turkish Statistical Institute (TUIK) (URL2), and climate data were obtained from the General Directorate of Meteorology (URL3).

In ML models, cultivated area, average humidity, average temperature, total sunshine time, and average precipitation were used as input variables, and production amount was used as the output variable. In practice, firstly, the missing values in the input and output variables were removed and the normalized values of the remaining variables were calculated. "Min-Max Normalization" method was used to normalize the variables (Eq. 1).

$$X^{\iota} = \frac{X - X_{min}}{X_{max} - X_{min}} \quad (1)$$

where X^{ι} is the normalized data, X is the actual data, X_{min} is the minimum value of dataset, and X_{max} is the maximum value of dataset.

For these variables 58-year of data for Edirne province were provided. The 58-year data set was prepared divided into two groups, 70% of which was training (58×0.7=40.6 ≈ 41 years) and 30% was testing (58×0.3=17.4 ≈ 17 years). The first 3 and last 3 rows of the dataset are given due to space constraints (Table 1).

Table 1. Data set

Year	Production amount (ton)	Cultivated area (hectares)	Average humidity (%)	Average temperature (°C)	Total sunshine duration (hours/day)	Average precipitation (mm)
1960	21198	25080	65.22	18.77	261.30	64.05
1961	15582	20440	61.72	19.82	295.37	40.32
1962	8613	14600	57.90	20.50	316.17	33.32
.	.	.	.	.	.	.
.	.	.	.	.	.	.
.	.	.	.	.	.	.
2019	249569	95050	60.75	21.78	296.65	40.60
2020	240434	90916	61.15	21.83	259.62	39.37
2021	285286	107351	64.12	21.43	254.83	35.50

Descriptive statistic values of input and output variables are given in Table 2. As seen in Table 2, the descriptive statistics values showing the changes in input variables such as standard deviation, variance, and range are quite different. A similar situation is also valid for the output variable, production amount.

Table 2. Descriptive statistics of input and output variables

Input/Output Variables	Mean	Standard Deviation	Variance	Median	Minimum	Maximum	Range
Production amount (ton)	156330	75903.8	5761384658	162623	8613	332894	324281
Cultivated area (hectares)	97958.3	34967.0	1222692893	107658	14600	142665	128065
Average humidity (%)	61.6124	2.97277	8.83737	61.3083	53.2000	69.5333	16.3333
Average temperature (°C)	20.3480	1.00153	1.00306	20.1250	18.7667	22.9000	4.13333
Total sunshine duration (hours/day)	273.720	18.8482	355.256	271.366	232.464	316.167	83.7025
Average precipitation (mm)	40.3052	12.2119	149.130	37.9833	17.5167	73.6667	56.1500

2.2. Machine Learning Methods

In the literature, SVM, DT, and RF methods are used for modeling and performance evaluation in estimation problems. SVM finds the most appropriate hyperplane to classify data and generally works effectively with high-dimensional data. While DT uses a series of simple decision rules to classify data, RF increases the generalization ability by creating a collection of these trees. Hyperparameter optimization aims to find the best parameter values in the structure or operation of the method to increase the performance of the model. The halving grid search method allows training to be done on a smaller data set instead of the data set to be examined and to obtain more efficient results in a shorter time with fewer operations. Finally, statistical performance criteria such as RMSE and MAE are used to measure the success of the model, evaluating the efficiency and reliability of the models. Each of these methods plays an important role in solving estimation problems and helps to obtain the best results by complementing each other.

2.2.1. Decision Tree Method

The DT has a hierarchical tree structure consisting of nodes called root node branches, decision nodes, and leaf nodes (Rokach and Maimon, 2014). DT is a tree-structured classifier, where decision nodes, branches, and each leaf represent the features of a dataset, the decision rules, and the outcome, respectively. In a DT, for predicting the given dataset, the algorithm starts from the root node of the tree and passes through the decision node to the last leaf node, thus creating a branch (Figure 2).

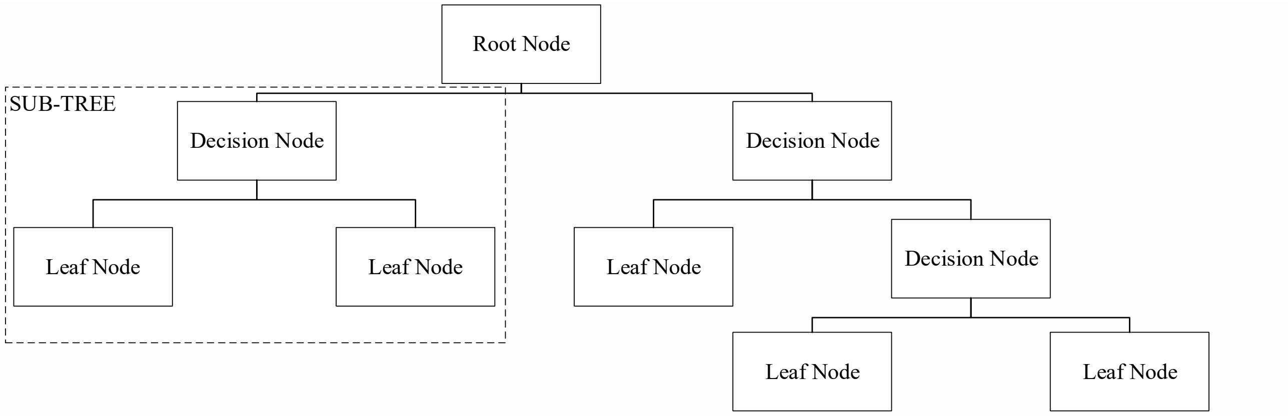


Figure 2. DT Structure

In the tree, classes are represented by leaves, and only one road goes to each leaf. While creating the tree, yes-or-no questions are asked. In this algorithm it is compared the values of the root attribute to the record (real dataset) attribute and, according to the comparison result, followed the branch and jumped to the next node. In the next node, it compares the attribute value to the other sub-nodes again and moves further. It continues the process until it reaches the leaf node of the tree.

2.2.2. Support Vector Machine Method

SVM is an ML algorithm used for linear or nonlinear classification and regression. SVM is an ML algorithm used for linear or nonlinear classification and regression. SVM is an easy, adaptable, and efficient method because it can manage high-dimensional data and nonlinear relationships (Cortes and Vapnik 1995). SVM regression is a regression method maintaining all the main features that characterize the SVM algorithm (maximal margin). SVM regression is a powerful tool to explain complex relationships between the input variables and the target variable. The method aims to find the hyperplane that passes through as many data points as possible within a certain distance, called the margin, instead of fitting a line to the data points (Figure 3). SVM handles non-linear relationships between input variables and the target variable using a kernel function and thus it reduces the prediction error.

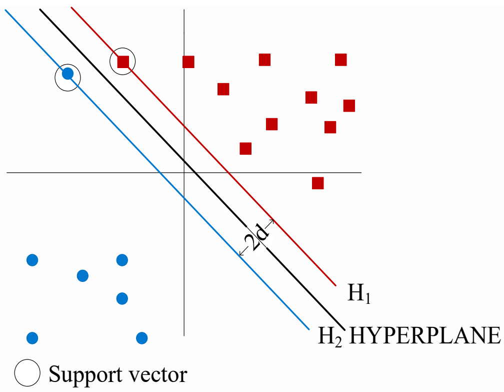


Figure 3. Support Vector and Hyperplane Structure

2.2.3. Random Forest Method

RF used to predict continuous outcomes, is one of the popular ML methods (Breiman 2001). RF is an ensemble technique with the use of multiple DTs. In other words, it is RF containing many trees constructed in a "random" way form. It is called Bootstrap and Aggregation because of it is combined multiple DTs in determining the final output instead of evaluating individual DTs. Each tree is formed from a different sample of rows and at each node of tree it is selected a different sample of features for splitting. Trees make individual predictions. These predictions are then averaged to produce a single result (Figure 4). RFs generally outperform DTs. However, RF method's performance can be affected by data characteristics.

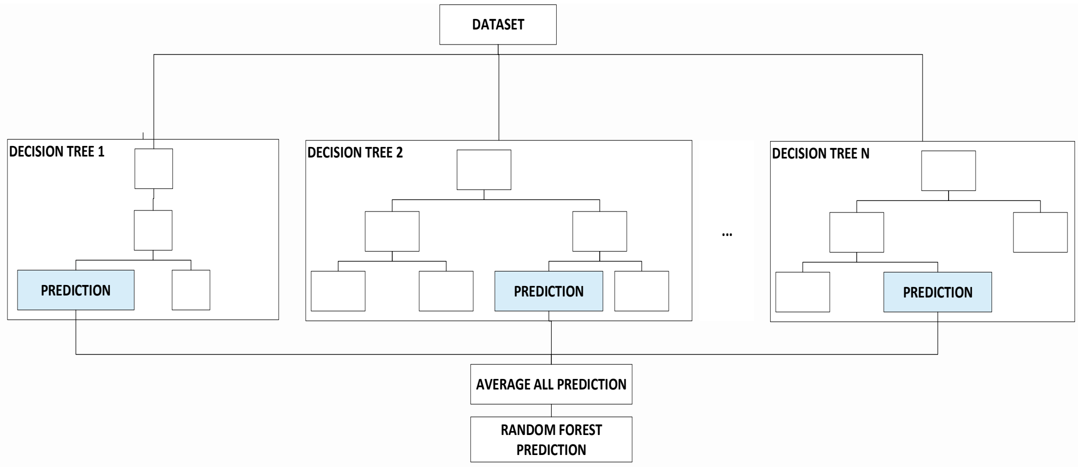


Figure 4. RF Structure

2.2.4. Hyperparameter Tuning and Halving Grid Search

ML methods contain a large number of hyperparameters that affect their performance. These hyperparameters have a wide range of values when it is determined by expert experience or by examining different studies in the literature. Therefore, the hyperparameter value may result in poor performance. This is because each ML method has its own best set of hyperparameter values that can vary according to different or updated input data (Salam and El Hibaoui 2021; Xu et al. 2021). Therefore, it is necessary to use hyperparameter tuning approaches that enable even inexperienced users to achieve good performance. In the literature, the grid search (GS) method is a frequently used method for hyperparameter tuning due to its ease of use (Hadjout et al. 2022; Aouad et al. 2022). The GS method aims to run ML methods for all combinations of hyperparameter values within the value range defined by the user and to obtain the combination that gives the best results. As the number of hyperparameters increases, the number of combinations to be processed increases, which is time-consuming and has high computational costs. In order to eliminate this disadvantage of the GS method, HGS method is used. In the method, all possible combinations of hyperparameters are trained on a small subset of data rather than the entire training data, fewer transactions are carried out in less time.

2.2.5. Performance Evaluation Criteria

The MAE, MAPE, RMSE, and R^2 are the most commonly used criteria when evaluating model performance (Chung et al. 2022; Cui 2022; Tang et al. 2024; Yan et al. 2024). In prediction problems, the prediction error between the predicted value and the actual value must be minimal. Therefore, statistical performance criteria such as MAE, MAPE, and RMSE were used. In addition, statistical performance criteria are used to determine prediction accuracy. Therefore, the R^2 value was calculated. R^2 is the coefficient of determination that provides information about the goodness of fit of a model and takes values between 0 and 1. While an R^2 value closer to 0 indicates that the prediction is incompatible with the data, and the value of 1 indicates that the regression predictor fits the data perfectly.

The performance evaluation criteria used are given in Eqs. 2-5, respectively.

$$MAE = \frac{1}{N}\sum_{i=1}^{N}|T_i - P_i| \quad (2)$$

$$MAPE = \frac{1}{N}\sum_{i=1}^{N}\left|\frac{T_i - P_i}{T_i}\right| \quad (3)$$

$$RMSE = \sqrt{1/N\sum_{i=1}^{N}(T_i - P_i)^2} \quad (4)$$

$$R^2 = \left[\frac{\sum_{i=1}^{N}((T_i-\bar{T})(P_i-\bar{P}))}{\sqrt{\sum_{i=1}^{N}(T_i-\bar{T})^2\sum_{i=1}^{N}(P_i-\bar{P})^2}}\right]^2 \quad (5)$$

where T_i is i^th actual data, $\bar{T}$ is the mean of actual data, P_i is the i^th predicted output data and $\bar{P}$ is the mean of i^th predicted output data in the dataset.

2.3. Study Area

Edirne province is one of the most province in sunflower cultivation in Turkey. In 2021, 285,286 tons of sunflower production were realized from 1,073,508 decares of cultivated area in Edirne province. Edirne province's latitude and longitude are 26 E 34 and 41 N 40, respectively (Figure 5).

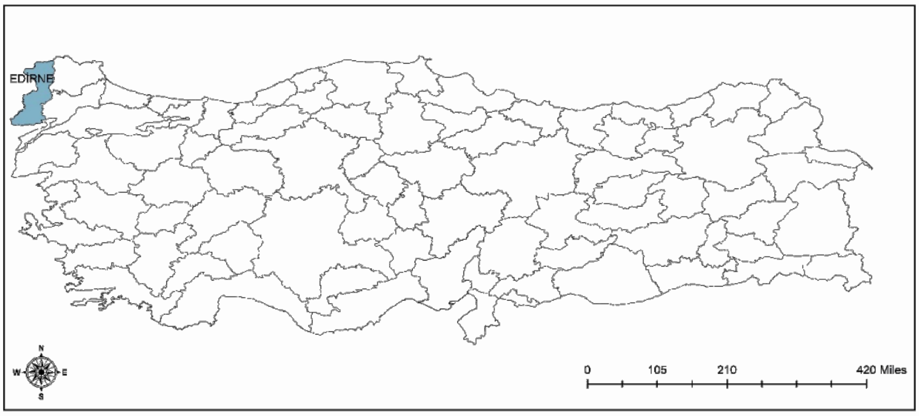


Figure 5. Edirne province in Turkey

Edirne is a transition region under the influence of both the Mediterranean climate and the continental climate peculiar to Central Europe. It has suitable conditions in terms of humidity, temperature, rain, and duration of sunshine. The annual average temperature is 13.4 °C, precipitation is 585.9 mm, and relative humidity is 70%.

3. Implementation

3.1. Definition of Model

In this study, DT (Iniyan et al. 2023; Singh and Singh 2017; Kalichkin et al. 2021), SVM (Priyadharshini et al. 2022; Gandhi et al. 2016; Gonzalez-Sanchez et al. 2014), and RF (Everingham et al. 2016; Fukuda et al. 2013), which are the most used ML methods for crop yield prediction in the literature (Debaeke et al. 2023), were selected to predict annual yield in Edirne. Furthermore, Benos et al. (2021) examined the studies in which ML methods were used for yield prediction in the literature and determined that the ones that gave the best output were ANN, SVM and DT, respectively.

As a result of the examination of the related studies in the literature, five variables that are thought to affect the sunflower yield were determined. They are cultivated area (Gonzalez-Sanches et al. 2014.; Gandhi et al. 2016), average humidity (Laxmi and Kumar 2011; Dahikar and Rode 2014), average temperature (Jiang et al. 2004; Kaul et al. 2005; Thonhboonnak et al. 2011; Laxmi and Kumar 2011; Dahikar and Rode 2014), total sunshine duration (Jiang et al. 2004; Thonhboonnak et al. 2011), and average precipitation (Kaul et al. 2005; Liu et al. 2001; Laxmi and Kumar 2011; Thonhboonnak et al. 2011; Dahikar and Rode 2014). While the cultivated area and yield of sunflowers are considered on an annual basis, the climate elements (temperature, humidity, precipitation, sunshine duration) are taken as the average of the 6 months between April and September, which is the production period of sunflower (Mishra et al. 2016; Jain et al. 2017; Paudel et al. 2021). Yield is expressed in tons of crop grown per hectare or decare in arable regions. The cultivated area is agricultural lands where the sunflower plant is grown for one year. The average humidity is the average concentration of water vapor present in the air. The average temperature of the air as indicated by a properly exposed thermometer during a given time period, such as a day, a month, or a year. The average sunshine duration is the average length of time that the ground surface is irradiated by direct solar radiation. The average precipitation is the average amount of weather events such as rain and snow that occur as a result of the condensation of water vapor in the atmosphere.

3.2. Implementation of HGS Method

The hyperparameter combinations determined using HGS for ML methods in the study are shown in Table 3.

Table 3. Hyperparameters of methods

	SVM	RF	DT
Hyperparameters	Gamma parameter	Number of trees	Confidence parameter
	C parameter	Maximum depth	Minimum number of leaves
	Max number of iterations	Prepruning	Prepruning
	Kernel cache		Pruning
	Kernel type		Maximum depth

All hyperparameter combinations created in accordance with the given lower and upper limits were solved by the grid search method, and since all hyperparameter combinations were tried, the hyperparameter combination with the best performance value was obtained.

In the SVM method, it has been determined by the HGS method that there are five hyperparameters that affect the prediction result. For the determined hyperparameters, 58564 combinations were created in the grid search method, and the minimum and maximum values used are summarized in Table 4. Also, "dot", "radial", "neural" and "anova" are used as kernel type.

Table 4. Hyperparameters values for the SVM method

Hyperparameters	Min	Max	Number of steps
Gamma parameter	0	100	10
C parameter	0	100	10
Max number of iterations	1	100	10
Kernel cache	0	100	10

The hyperparameters of SVM with the best RMSE value are radial kernel type, 80 kernel cache, 80 max iterations, 20 C, and 30 Gamma. Test data values of predicted and actual production amounts using the SVM method are shown in Figure 6.

A total of 58 support vectors were used in the SVM method and a bias of 0.457 was obtained. The weights calculated with the SVM method are seen in Table 5.

Table 5. Input variable weights obtained with SVM

Cultivated area (hectares)	Average humidity (%)	Average temperature (°C)	Total sunshine duration (hours/day)	Average precipitation (mm)
1.928	0.661	1.281	0.239	0.271

Since the values in the data set are numerical in the RF method, the 'least-square' separation criterion was used. By using the HGS method, it was determined that three important parameters affect the prediction performance. Therefore, the grid search method was applied for these three hyperparameters (Table 6).

Table 6. Hyperparameters and values used for the RF method

Hyperparameter	Min	Max	Number of steps
Number of trees	1	100	100
Maximum depth	0	100	100
Prepruning	√	X	

Applied: √ Not applied: χ

After determining the hyperparameters suitable for the RF model, prediction values were calculated with the proposed algorithm. The hyperparameters of the RF with the best RMSE values are the combination of 3 tree count, 55 maximum depth, and no preprunning.

Test data values of predicted and actual production amounts using the RF method are shown in Figure 7.

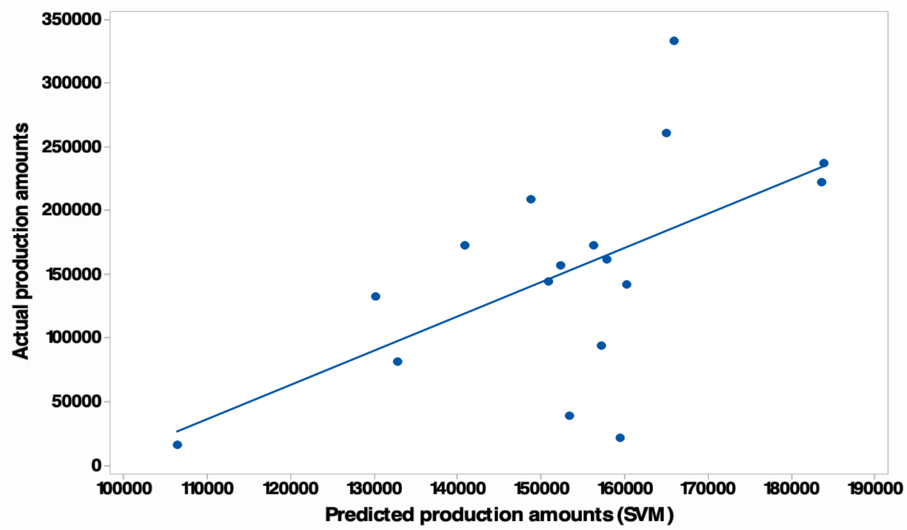


Figure 6. Actual and predicted production amounts using SVM method

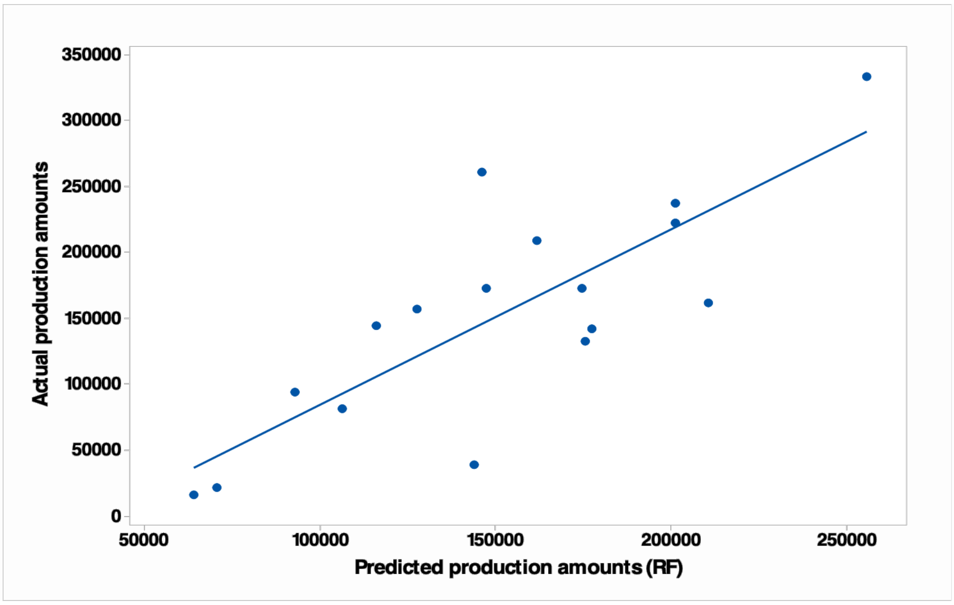
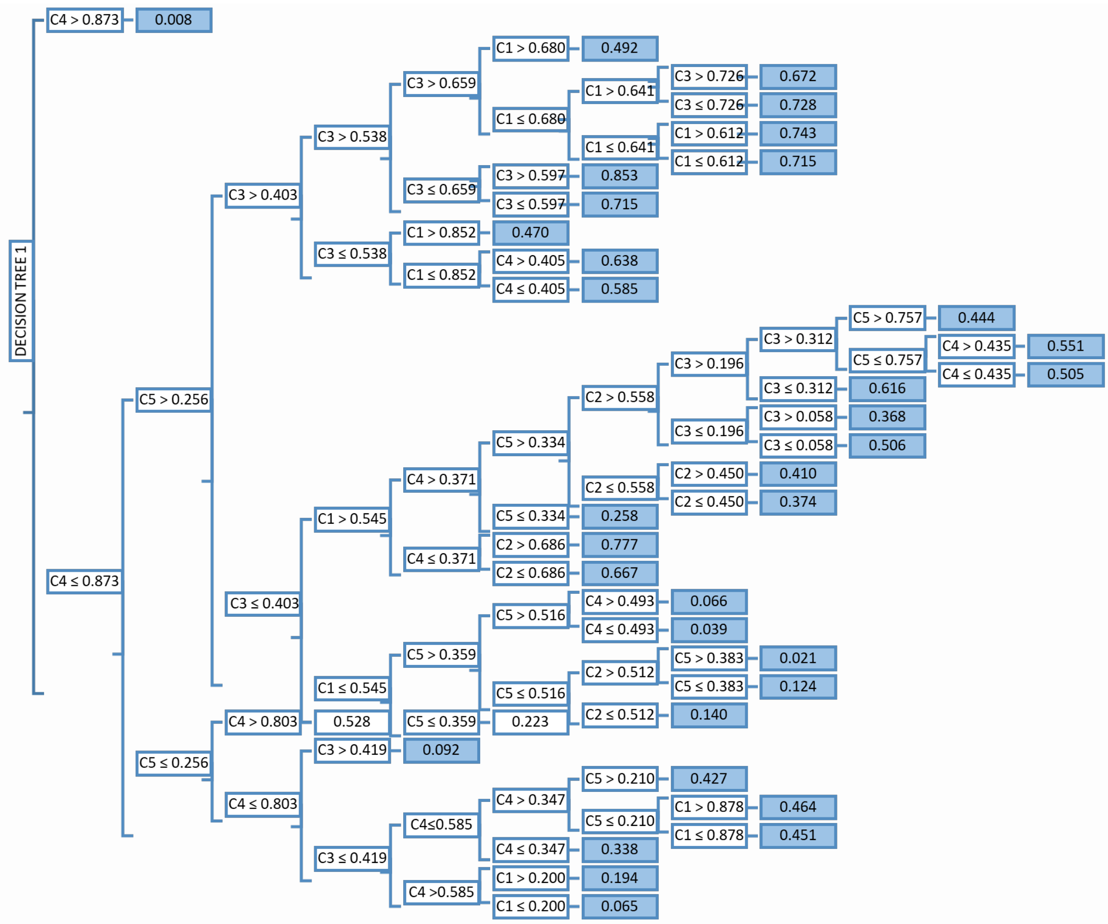


Figure 7. Actual and predicted production amounts using RF method



C1: Cultivated area C2: Average humidity C3: Average temperature C4: Total sunshine duration C5: Average precipitation

Figure 8. The first created DT for the RF method

Due to space constraints, one of the three created DTs for the RF method is shown (Figure 8). Final prediction values were obtained by taking the arithmetic average of the values obtained using three DTs.

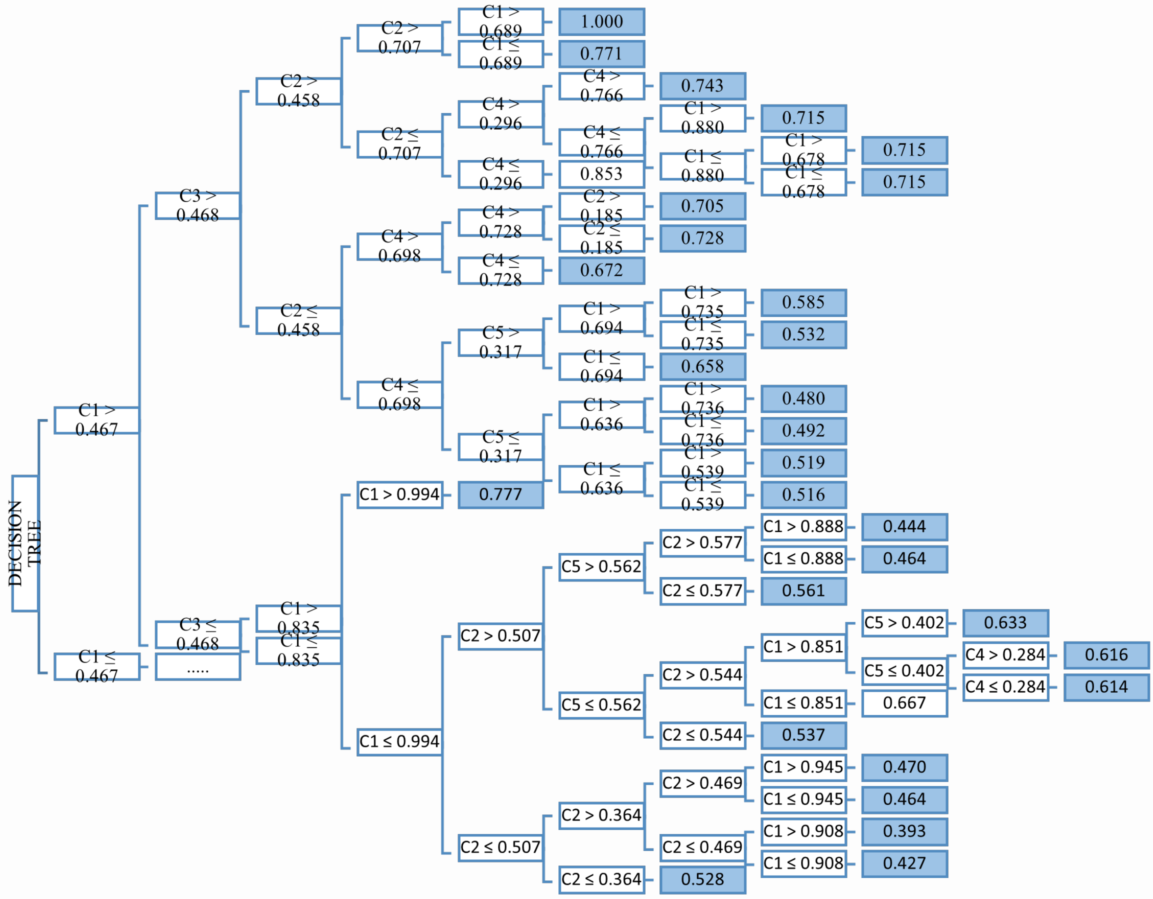
In the DT method, least squares method was used as the splitting criterion. Hyperparameters used are also shown in Table 7.

Table 7. Hyperparameters and values used for the DT method

Hyperparameter	Min	Max	Number of steps
Confidence parameter	0	1	10
Minimum number of leaves	1	100	10
Prepruning	√	χ	
Pruning	√	χ	
Maximum depth	0	100	10

Applied: √ Not applied: χ

In the method, 5324 combinations were created for 5 hyperparameters, and RMSE values were obtained. The iteration that gives the best prediction result has 20 maximum depth, 0.8 confidence parameter, 51 minimum number of leaves, no pruning and no prepruning hyperparameters. Test data values of predicted and actual production amounts using the DT method are shown in Figure 9. Additionally, the created DT is shown in Figure 10.



C1: Cultivated area C2: Average humidity C3: Average temperature C4: Total sunshine duration C5: Average precipitationa

Figure 10. The created DT

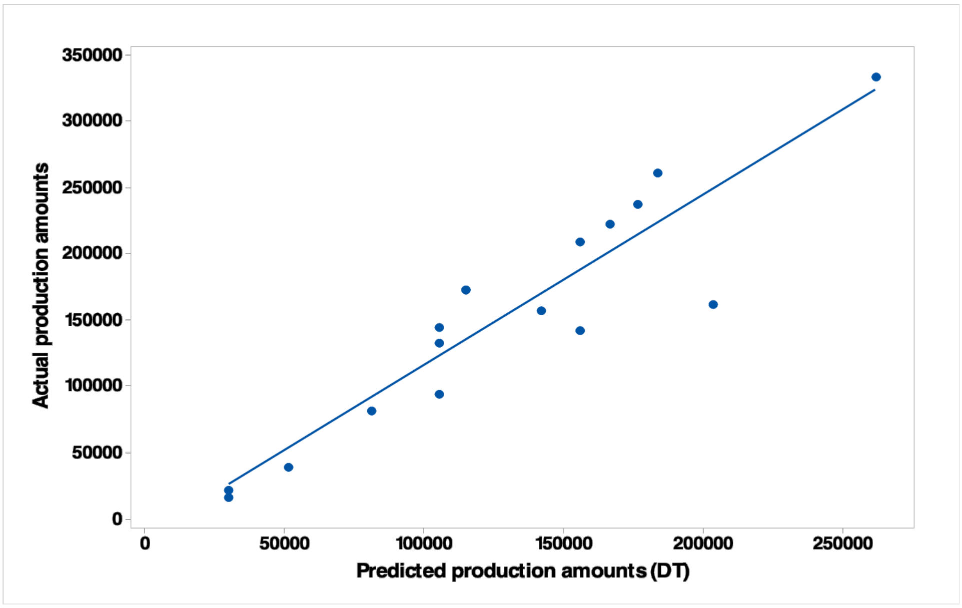


Figure 9. Actual and predicted production amounts using DT

In Figure 11, the closest predicted values to the actual production amount are determined by the DT method with hyperparameters determined with HGS.

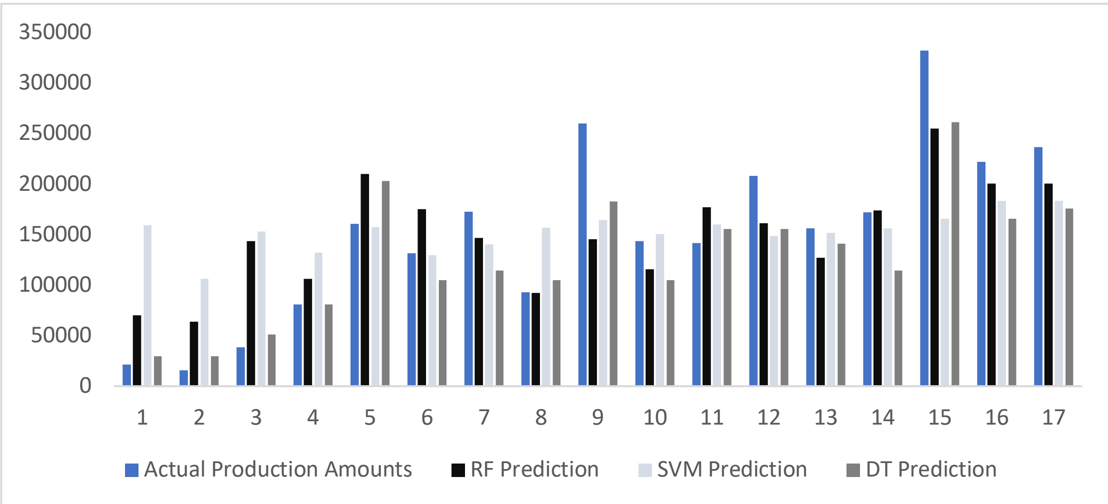


Figure 11. Actual and predicted production amounts using ML methods

4. Results

4.1. Results for comparison of the machine learning methods

The prediction result obtained using the DT method and the actual sunflower yield are 95 % similar. At the end of the application, the DT method was compared with other ML methods such as SVM, and RF. Rapidminer Studio program was used for all ML applications. In Table 8, the performance evaluation criteria for the training and testing data of the prediction methods are separately shown.

When the MAE values are examined, the DT model provides the lowest error in both training data (0.112) and test data (36352.03). While the RF model has higher error rates, with 0.138 in training data and 43436.89 in test data, the SVM model shows the highest error, with 0.268 in training and 58919.2 in test data.

Similarly, when the MAPE statistical performance criterion is evaluated, DT provides the best results in both training (0.263) and testing (0.274). The highest error is obtained in the SVM method.

When examined in terms of RMSE, DT again has the lowest error values, with 0.164 in training and 43618.12 in test. In test data, RF (52865.08) and SVM (65986.54) methods perform weaker than DT.

R^2 values show the success of the model. DT shows the best fit with 0.954 in training and 0.920 in testing. RF shows a strong performance in training (0.939) but slightly drops in test data (0.800). SVM's R^2 values in training (0.720) and test (0.680) data show lower performance compared to other models.

Finally, when training time is taken into account, DT is the fastest model, training in just 23 seconds. RF and SVM models were trained in longer times, 945 and 884 seconds, respectively.

Table 8. Comparison of the machine learning methods

Performance Criteria	Methods					
	DT		RF		SVM	
	Train	Test	Train	Test	Train	Test
MAE	0.112	36352.03	0.138	43436.89	0.268	58919.2
MAPE	0.263	0.274000	0.378	0.651	0.554	1.10000
RMSE	0.164	43618.12	0.179	52865.08	0.242	65986.54
R^2	0.954	0.920	0.939	0.800	0.720	0.680
Training Time (second)*	23		945		884	

* These are the total training times used to solve selected optimum hyperparameter combinations with HGS

In order to see the advantage of the HGS method, the DT method is solved with max depth (P_1), pruning (P_2), confidence parameter (P_3), pre-pruning (P_4), minimum number of leaves (P_5), minimum division (P_6), and pre-pruning (P_7) parameters without using HGS. Table 9 includes the criteria used, the number of combinations, performance criteria, and solution times.

Table 9. Solution of DT method with different hyperparameters

Parameter P_1	P_2	P_3	P_4	P_5	P_6	P_7	Number of parameter	Number of combinations	RMSE	AE	RRSE	R^2	Time (second)
√	√	√	√	√	√	√	7 parameter	644204	0.078	0.063	0.332	0.89	4608
	√	√	√	√	√	√	6 parameter	58564	0.091	0.074	0.434	0.84	432
√		√	√	√	√	√	6 parameter	322102	0.086	0.066	0.336	0.88	1759
√	√		√	√	√	√	6 parameter	58564	0.091	0.074	0.434	0.84	223
√	√	√		√	√	√	6 parameter	322102	0.086	0.660	0.366	0.88	3056
√	√	√	√		√	√	6 parameter	58564	0.054	0.042	0.213	0.95	433
√	√	√	√	√		√	6 parameter	58564	0.054	0.042	0.213	0.95	894
√	√	√	√	√	√		6 parameter	58564	0.054	0.042	0.213	0.95	894
√	√	√	√	√			5 parameter *	5324	0.054	0.042	0.213	0.95	23

* Hyperparameters determined by HGS method

The RMSE, AE, and RRSE error values obtained with 644204 combinations using 7 parameters are 0.078, 0.063, and 0.332, respectively. Although the model also provides reasonable results in terms of R^2 value (0.89), it was the sample trained in the longest time with a training time of 4608 seconds.

Among the other combinations made with 6 parameters, the sample without the P_5 parameter draws attention. This sample has the best results in terms of RMSE (0.054), AE (0.042), RRSE (0.213), and R^2 (0.95), and its training time is 433 seconds.

Finally, the sample determined by the HGS method with 5 parameters gave the lowest RMSE (0.054), AE (0.042), RRSE (0.213), and R^2 (0.95) results, while it was the fastest model with a training time of only 23 seconds. This combination offers the most ideal solution in terms of both accuracy and speed. In summary, while increasing the number of parameters increases the complexity and training time of the model, the combinations with the best performance were 5 and 6 parameter models. In particular, the model determined with the HGS method stands out with the lowest error rate and the shortest training time.

At the end of the solutions obtained, it is seen that the performance criteria of the HGS method get better values, and the solution time is shortened.

4.2. Statistical method

In the study, MINITAB 18 program was used for statistical method solutions.

An ANOVA test was applied using the absolute values of the difference between the predicted and actual production amounts. The fact that the p value is less than 0.05 as a result of the test shows that the accuracy results between DT, RF, and SVM are statistically significant (Table 10). This low p-value indicates that the factors have an effect on the model, and the null hypothesis (that the factors have no effect) can be rejected. Accordingly, the p-value is less than 5 percent, and the H_0 hypothesis is rejected. In other words, there is a difference between the groups.

Table 10. Result of ANOVA

Source	DF	Adj SS	Adj MS	F	p
Factor	2	1.71848E+11	57282528009	9.00	0.000
Error	64	4.07500E+11	6367192115		
Total	66	5.79348E+11			

In addition, standard deviations of the absolute value of the difference between the predicted and actual yield for each method were calculated. It was seen that the DT method gave the smallest standard deviation (Table 11).

Table 11. Mean and standard deviation of method

Factor	N	Mean	Standard Deviation
RF	17	43437	31060
SVM	17	149569	110780
DT	17	36352	24847

The standard deviation value for RF is 31060, indicating that there is a certain degree of deviation in RF's prediction.

The standard deviation value of the SVM method is also quite high, indicating that SVM predictions show a large variability. SVM performs the worst in terms of both mean and deviation.

The DT method, on the other hand, has the lowest value in terms of both mean and standard deviation. This shows that DT gives more consistent and reliable results compared to other methods.

As a result, the DT method shows the best performance with both a low mean and a low standard deviation. Although RF exhibits slightly higher error rates compared to DT, it still shows reasonable performance. SVM stands out as the method that gives the worst results in terms of both mean and standard deviation.

5. Conclusion

The production of sunflower, one of the most important crops, varies due to fluctuations that occur every year. In the study, sunflower production was predicted with ML methods, that are frequently used in environments where such variability is high. The biggest challenge in machine learning methods is determining the hyperparameter combinations and values that affect prediction performance. For this reason, the combination of hyperparameters to be used in the models was determined using the HGS method. At the end of the application, the DT hyperparameter combination that gave good results was determined as the maximum depth, pruning, confidence parameter, pre-pruning, and minimum number of leaves. In addition, by using HGS in DT, results were obtained with 95% accuracy level in a short time of 23 seconds. RF and SVM methods, with 945 and 884 seconds, respectively, have been less successful than DT. Finally, with the ANOVA test, it was verified that ML methods used have different prediction capabilities.

The best prediction result was obtained with DT method based on the HGS method. Thus, with the DT model, the production amount for the coming years can be estimated for all sunflower-growing provinces according to the changing amounts of inputs. The amount to be imported, which cannot be met from the total predicted product amount, can be determined. In this way, the problems of keeping stock in case the imported quantity is larger than necessary and not being able to meet the demand if it is less will be prevented.

6. Discussions

Machine learning methods are used to obtain accurate results in prediction problems. Each of the machine learning methods has advantages and disadvantages. For example, SVM provides high accuracy, but it has high computational cost and kernel selection difficulties in large data sets. DT, although highly interpretable, has the risk of overfitting and may be inadequate in modeling complex data. RF increases the generalization ability of the model but may bring large computational and memory costs.

One of the biggest disadvantages of machine learning methods is the need to determine many hyperparameters, both structurally and operationally. This study aims to determine the hyperparameters of machine learning methods using HGS in a shorter time and with less workload. In practice, the HGS method has been applied to machine learning methods such as DT, RF, and SVM. The method that provides the best performance value criteria is DT. Additionally, by performing an ANOVA test, it was confirmed that the method with the lowest standard deviation was the DT method.

In future studies, it is aimed to determine the hyperparameters of the machine learning methods used by using different optimization methods. In addition, it is aimed to examine the accuracy of the model by using the developed model in different regions where sunflower production is carried out.

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Detecting Wheat Leaf Diseases: A Deep Feature-Based Approach with Machine Learning Classification

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HIGHLIGHTS

- This study introduces a methodology aimed at early diagnosis of wheat leaf diseases.
- The approach relies on deep features to achieve high precision and accuracy in identifying diseases.
- Various machine learning models are employed to effectively classify wheat leaf diseases.
- The developed method ensures high accuracy rates in disease detection, contributing to increased agricultural productivity.

Abstract

Wheat is a rich storehouse of nutrients with many different vitamins and minerals. Wheat is one of the main cereals that meet the nutritional needs of humans and other living things and is used in the production of other foods. It can be grown in almost all regions of the world. It requires less irrigation compared to other plants. One of the most important problems in wheat cultivation is the fight against diseases. Wheat diseases cause yield losses and quality decreases as in other agricultural products. Timely and accurate diagnosis of these diseases; It is clear that it will lead to an increase in yield and quality. Detection of these diseases with the naked eye can be difficult and laborious. In this study, diseases on wheat leaves were detected using image processing techniques. The features of septoria and stripe rust diseases on wheat leaves were extracted using pre-trained networks VGG-16, VGG-19 and then classified with machine learning algorithms support vector machines (SVM), multi-layer perceptron (MLP), k-nearest neighbor (KNN). The results obtained were evaluated with performance criteria such as accuracy, sensitivity, specificity, precision and F1-Score. In the analysis, the features extracted with VGG-19 were classified with SVM method and the highest classification accuracy of 98.63% was achieved.

Keywords: Wheat leaf disease; Deep features; Deep learning

1. Introduction

Wheat, the most important cereal crop, is directly related to human survival and progress (Wen et al. 2023). Wheat is an annual plant species and is suitable for growing in cool climatic conditions. Variety, climatic conditions and soil characteristics affect the quality production of wheat. Wheat continues to be the most-produced cereal in the world (Atar 2017).

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Wheat grain contains 14% protein, 14% starch and other nutrients such as fiber, vitamins, minerals and high-quality amino acids. Wheat was previously vital to the global diet due to its high nutritional value and excellent storage qualities. For modern food production, key wheat-derived resources such as wheat starch and wheat proteins are essential. Up to 20% of our daily caloric intake comes from bread and bakery products, which are essential for nutrition (Long et al. 2023).

In many countries in Asia, changes in grain quality to meet increasing wheat consumption require additional crop production. Continuous breeding efforts to improve yield and quality also face challenges (Figueroa et al. 2018).

One of the most important factors in wheat production is the quality of the wheat plant. If the seed quality decreases, the quality of wheat production also decreases. Diseases are the leading cause of poor quality (Özkan et al. 2021). Wheat rust, wheat powdery mildew, wheat scab, etc. are common diseases of wheat leaves (Wen et al. 2023).

Detection of plant diseases with the naked eye can be difficult and laborious. In recent years, many image-processing techniques have been used in the field of agriculture for disease detection. Detection and diagnosis of plant diseases using image processing techniques are very advantageous in terms of time, cost and convenience. Disease diagnosis with traditional methods used in the past causes a lot of labour and wasted time (Çetiner 2021).

Two of the diseases seen on wheat leaves and mentioned in the study are mentioned below:

Septoria disease is a disease that causes a decrease or even loss of crop production and yield in wheat. This disease, whose pathogen name is zymoseptoria tritici, reduces wheat yield by 30% to 50%. This disease, which is widespread in Turkey as in many countries, causes significant crop losses in wheat (Kilinç et al. 2021). This disease starts on the underside of the leaf and spreads to the upper part of the leaf. Symptoms appear as lesions with a light or dirty-colored center that can be clearly distinguished from the green part of the leaf. These lesions can spread to other healthy wheat leaves by spreading to areas where wind is effective. As the disease progresses, these lesions turn into spots and turn ash-colored (Mustafa 2020).

Stripe rust, or yellow rust disease, is a disease that causes a decrease in production and yield as in Septoria disease. This disease was first described in wheat by Gadd in 1777 in Europe. The pathogen causing this disease is now called P. striiformis. This disease is carried by the wind as the most important factor to every area where wheat production is carried out far away from each other, and it has been found that the spores of the disease agent can also be carried by people's belongings and clothes. The disease can be seen in climatic conditions with warm temperatures and high humidity. This disease, which is generally seen on the upper parts of the leaves, is also seen on the stems and ears of wheat. This disease, which resembles yellow-colored machine stitching, is also called line rust because it forms line-like areas on the leaves (Çat et al. 2017).

These diseases threaten wheat production and quality all over the world and also threaten countries whose economies and livelihoods depend on wheat (Figueroa et al. 2018).

1.1 Literature Review

In this section, studies on wheat leaf diseases in the literature are mentioned.

Xu et al. (2023) classified five classes with various pre-trained networks using a dataset of 7239 wheat leaf images. They used ZFnet, VGG-19, Incetion V4 and EfficientNet-B7 and their own proposed RFE-CNN models. They obtained 99.95% classification accuracy with RFE-CNN.

Cheng et al. (2023) obtained 96.4% classification accuracy with Resnet50 using a dataset of wheat leaf and spike images consisting of five classes.

Sheenam et al. (2023) classified a total of three classes of wheat leaves (healthy and two types of diseases) with an improved model of VGG19 from pre-trained networks. They improved a dataset of 1266 wheat leaf images and achieved 97.65% classification accuracy with VGG19.

El-Sayed et al. (2023) used a dataset consisting of three classes. The dataset they studied consists of 407 wheat leaf images. VGG16, VGG19 and InceptionResNetV2 were used as pre-trained networks in the analysis. They achieved 98% classification accuracy with VGG19.

A. ruby et al. (2022) used a dataset consisting of four classes. The dataset they studied consists of approximately 4,500 wheat leaf images. InceptionV3, DenseNet, ResNet50 and their own proposed ResNet50 were used as pre-trained networks in the analysis. They obtained 98.44% classification accuracy with their proposed ResNet50.

Bukhari et al. (2021) used a dataset consisting of three classes in their study. The dataset they studied consists of 310 wheat leaf images. They used three different segmentation techniques: Watershed, GrabCut and U2-Net. They segmented with U2-Net with a rate of 96.19%.

Mrinal et al. (2017) used a dataset consisting of four classes in their study. The dataset they studied is publicly available LWDCD2020 and consists of 12160 wheat leaf images. ResNet152 and VGG19 were used in the analysis. They obtained 97.81% classification accuracy with ResNet152.

Khan et al. (2022) classified wheat leaves using machine learning and deep learning methods for three classes, two disease and one healthy. They achieved 99.8% classification accuracy using a fine-tuned RFC model.

Nigam et al. (2021) classified wheat leaves using deep learning methods for two classes: healthy and Rust disease. The dataset consists of 2,000 wheat leaf images. They obtained 97.37% classification accuracy using CNN in the analysis.

Long et al. (2023) used a dataset consisting of five classes, four diseased and healthy. They used 999 wheat leaf images in the dataset. MobileNet, InceptionV3, VGG16, Xception and CerealConv were used in the analysis. They obtained 97.05% classification accuracy with CerealConv.

Catal Reis & Turk (2024) classified three classes, two diseased and one healthy, using deep learning methods. They used 2400 wheat leaf images in the dataset. Thirteen models such as EfficientNetB2, MobileNet, Xception, NASNetMobile, InceptionV3, DenseNet121, DenseNet169, DenseNet201, RegNetY080, ResNet50V2, ResNet101V2, ResNetRS50 and ResNetRS101 were used for classification. With the proposed method, 99.72% classification accuracy was obtained in the analysis performed by using IDLF and EL model together.

Table 1. Summary of the literature review

Description of The Problem	Class	Methods	Accuracy	References
Wheat Leaf	5	RFE-CNN	99.95%	(Xu et al., 2023)
	5	ResNet50	96.4%	(Cheng et al., 2023)
	3	VGG19	97.65%	(Sheenam et al., 2023)
	3	VGG19	98%	(El-Sayed et al., 2023)
	4	Resnet50	%98,44	(A et al., 2022)
	3	U2-Net	%96.19	(Bukhari et al., 2021)
	4	ResNet152	%97.81	(Mrinal et al., 2017)
	3	Fine-tuned RFC model	%99.8	(Khan et al., 2022)
	2	CNN	%97.37	(Nigam et al., 2021)
	5	CerealConv	%97.05	(Long et al., 2023)
	3	IDLF ve EL	%99.72	(Catal Reis & Turk, 2024)
	2	VGG16 + SVM	98.63%	Our Study

Table 1 shows that different methods have been applied to detect wheat leaf diseases on different datasets and different class numbers. Our study can be considered as unique in this field.

2. Materials and Methods

This section of the paper provides theoretical information about the dataset used, feature extractors and classifiers, and performance metrics.

2.1. Dataset

A dataset of wheat leaf images was used in the study (Getachew 2021). This dataset consists of three categories: healthy wheat, septoria and stripe rust. The number of data in the original version of this dataset and our preprocessed version are given in Table 2. The original dataset contains 407 wheat leaf images, 102 healthy, 97 septoria diseased and 208 stripe rust diseased. The images are in JPG format and have a high resolution of 4000x6000 or 6000x4000.

Table 2. Data features and explanations for dataset

Image Types	Class, Image Count	Total
Wheat Leaf (Orginal)	Healthy=102, Septoria = 97, Stripe Rust=208	407
Wheat Leaf (Pre-processing)	Healthy =78, Septoria =97, Stripe Rust=181	356

The original version of this dataset was captured with high resolution in an uncontrolled environment. The original wheat leaf images are shown in Figure 1.

Figure 1. Sample images in the dataset (a) Healthy (b) Stripe rust (c) Septoria

Many of the images in the dataset have unnecessary areas as background images. For this reason, in this study we manually removed the backgrounds from the original images. The reason for removing the backgrounds is that these parts are unnecessary and have a negative impact on the classification success. Figure 2 shows the images with background removed. The reorganized dataset contains a total of 356 wheat leaf images, 78 healthy, 97 septoria diseased and 181 stripe rust diseased.

Figure 2. Examples of (a) Healthy (b) Stripe rust (c) Septoria pictures with cleaned backgrounds

In addition, some of the pictures in the original data set were not included in the analysis because the background was not removed. Therefore, the number of images in the original dataset is different from the number of images in this study.

The flowchart of the study is given in Figure 3. First, the images in the original dataset were preprocessed and unnecessary backgrounds were removed. Then, features are extracted with the help of VGG-16 and VGG-19 pre-trained networks and classified with SVM, MLP and KNN machine learning algorithms.

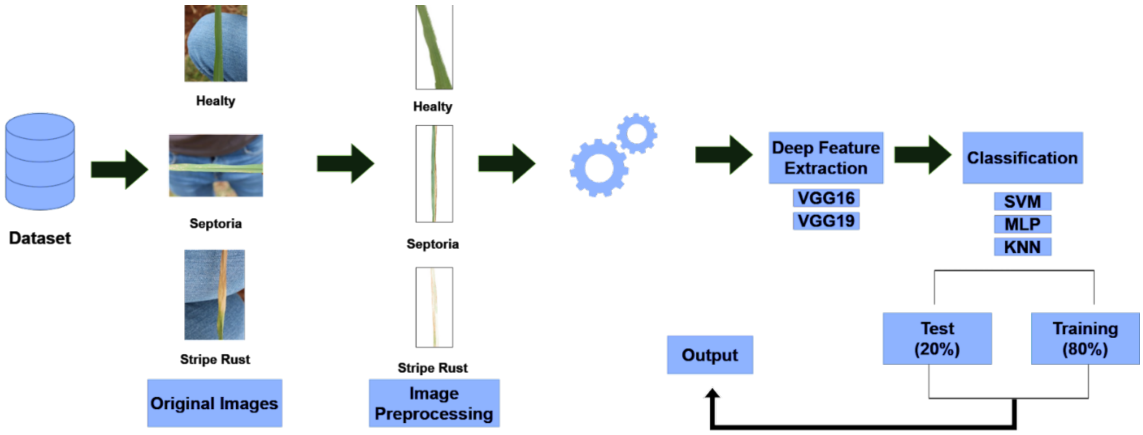


Figure 3. Graphical abstract of the study

Today, deep learning is seen as a sub-branch of artificial intelligence. Artificial intelligence started to become popular again in the early 2010s after losing interest during the so-called winter of artificial intelligence. One of the most important reasons for this interest is CNN models, which perform extremely well.

A pre-trained network, also known as a pre-trained network, is a deep learning model that has been pre-trained on large and complex data sets. Such models usually include learned weights that extract general features by learning examples from a large dataset (Dikici et al. 2022).

Deep learning techniques are not without their drawbacks. These deep learning techniques require a lot of data during the model's training (Avuçlu 2023). In situations when there is a shortage of data and computer power, transfer learning can also enhance classification performance (Goyal et al. 2021).

In this study, VGG-16 and VGG-19 pre-trained CNN models are used to extract features from wheat images. The theoretical descriptions of these models are given below.

2.2. VGG-16

VGG-16 is simple in terms of network model structure, but the most significant difference from previous models is that it is possible to use convolution layers in pairs or triples. This feature extraction model is transformed into a feature vector with 4096 neurons in the full connectivity layer. This model is a 16-layer model with approximately 138 million parameters. As we move from input to output, the width and height of the matrices decrease while the depth, i.e. the number of channels, increases (Gao et al. 2023).

2.3. VGG-19

VGG-19 is an improved model following VGG-16 and consists of 16 convolutional, 5 pooling, and 3 fully connected main layers. In other words, this feature extraction model consists of 24 main layers in total. Since VGG-19 has an in-depth network, the filters used in the convolutional layer are used to reduce the number of parameters. The size of each filter selected in this architecture is 3×3 pixels. The VGG-19 architecture has more parameters than the VGG-16 architecture and contains approximately 144 million parameters (Toğaçar et al., 2020).

2.4. SVM

Support vector machines (SVM) were developed by Vapnik et al. It is a learning method proposed by Vapnik for solving classification and curve-fitting problems based on statistical learning methodology and the principle of minimizing structural risk. This learning model belongs to the supervised learning model. SVM is divided into 3 main parts: linear separation, complete nonlinear separation, and nonlinear separation.

Recently, within the framework of statistical learning theory, Support Vector Machines (SVM) were developed and successfully used in numerous applications, from biological data processing for medical diagnosis to facial recognition and time series prediction (Karagül 2014).

2.5. MLP

In Multi-layer Perceptron (MLP), that is, Multi-layer Feed Forward Artificial Neural Networks, neurons are organized in layers. It consists of three layers: Input, Output and Hidden. The part between the Input and Output layers is called the Hidden layer. These networks can have more than one hidden layer. The processing units in the layers are interconnected. In MLP, the information analyzed by the input layer is imported into the system and the information processed by the output layer is exported. MLP emerged as a result of studies to solve the XOR problem. MLP works especially effectively in classification and generalization (Sarkar et al. 2023).

MLP is widely used as a supervised learning method or classifier in classification and regression applications in many areas such as pattern, voice recognition, classification problems. It works better on data that cannot be linearly separated. In general, it has superior performance in classification, prediction, recognition and interpretation (Erdem and Bozkurt 2021).

2.6. KNN

The K-Nearest Neighbor technique, also known as KNN, is a supervised machine learning technique that is mostly used for classification and regression issues in artificial intelligence. It is widely used for disease prediction. In general, the KNN algorithm can classify datasets using a training model similar to the test query by considering the k closest training data points (neighbors) that are closest to the query it is testing. In other words, in KNN-based classification, the distances between the test examples and the training examples are calculated and the K closest examples are selected. Among all machine learning algorithms, the KNN algorithm is one of the simplest forms and is widely used in classification applications because it has a design that is easy to implement and understand (Takci 2022).

2.7. Performance Metrics

In this section, benchmarking studies were carried out to analyze the classification performance of the pre-trained networks in the diagnosis of wheat leaf diseases. For this purpose, evaluation criteria such as accuracy, precision, recall and F1-Score were obtained with the help of confusion matrix. Accuracy is the ratio of the number of correctly predicted samples to the total number of samples in the dataset. Precision is the ratio of the number of correctly predicted diseased samples to the total number of samples predicted as diseased. Recall is a performance measure that expresses the ratio of true positives to total true positives and false negatives of a class. F1-Score is the weighted average of the sensitivity and precision parameters. It is preferred if the samples that make up the data set are unevenly distributed. These evaluation criteria can be expressed in the following formulas (Dikici et al. 2022).

$$\text{Accuracy} = \frac{\text{TP} + \text{TN}}{\text{TP} + \text{TN} + \text{FP} + \text{FN}} \tag{1}$$

$$\text{Precision} = \frac{\text{TP}}{\text{TP} + \text{FP}} \tag{2}$$

$$\text{Recall} = \frac{\text{TP}}{\text{TP} + \text{FN}} \tag{3}$$

$$\text{F1} - \text{Score} = 2 * \frac{\text{Precision} * \text{Recall}}{\text{Precision} + \text{Recall}} \tag{4}$$

3. Results

Experimental studies were carried out on the COLAB platform using a workstation with Intel ® Xeon (R) 2.20 GHz CPU, NVIDIA Tesla T4 16 GB GDDR6 GPU and 16 GB ram memory. The dataset used in the study includes 78, 181 and 97 images from samples classified as healthy, stripe rust and septoria, respectively.

Tablo 3. Hyperparameters of VGG-16 and VGG-19

Input size	224x224
Minibatch size	32
Max epoch	50
Learning rate	1e-5
Optimizer	Adam

Table 3 shows that the input size of VGG-16 and VGG-19 is 224x224, mini batch size is 32, max epoch is 50, learning rate is 1e-5 and optimized as 'man'. The parameters of SVM, one of the models used for classification in this study, are given in Table 4.

Table 4. Parameters of SVM

C	10
Kernel	rbf
gamma	0.0001

For SVM, C value was chosen as 10, kernel rbf and gamma value as 0.0001. The parameters of MLP, one of the models used for classification in this study, are given in Table 5.

Table 5. Parameters of MLP

Learning Rate	0.9
Momentum	0.7
Activation function	Sigmoid

For MLP, learning rate is 0.9, momentum is 0.7 and activation function is sigmoid. The parameters of the KNN model used for classification are given in Table 6.

Table 6. Parameters of KNN

K	2
Distance Metrics	Euclidean

The confusion matrices obtained from the experimental studies are presented separately for each model in Figure 4, Figure 5. In addition, the numerical values of the performance evaluation criteria are given in Table 7. As can be seen from Table 7, after feature extraction with VGG-19, SVM classification gives the best results in all performance criteria. The average accuracy, precision, recall, and F1-score of SVM classification are 98.63%, 0.98%, 0.98%, and 0.98% respectively. The second best results are obtained by MLP classification of the features extracted with VGG-19 and SVM classification of the features extracted with VGG-16. Accuracy is 95.89%, precision is 0.96, recall is 0.95, and F1-score is 0.95. SVM gave high classification accuracy for both feature extractions. MLP showed the second-best performance in the other classes as well. In this experimental study, KNN showed the lowest classification results in all performance evaluation criteria. The average accuracy, precision, recall and F1-score of KNN are 82.19%, 0.85%, 0.82% and 0.80% for VGG-16, respectively.

Table 7. Classification results of models with KNN, MLP and SVM using feature selection methods.

Feature Extractor	**VGG-16**			**VGG-19**		
	KNN	**MLP**	**SVM**	**KNN**	**MLP**	**SVM**
Accuracy	82.19%	94.52%	95.89%	79.45%	95.89%	98.63%
Precision	0.85	0.95	0.96	0.83	0.96	0.98
Recall	0.82	0.94	0.95	0.79	0.95	0.98
F1-Score	0.80	0.94	0.95	0.78	0.95	0.98

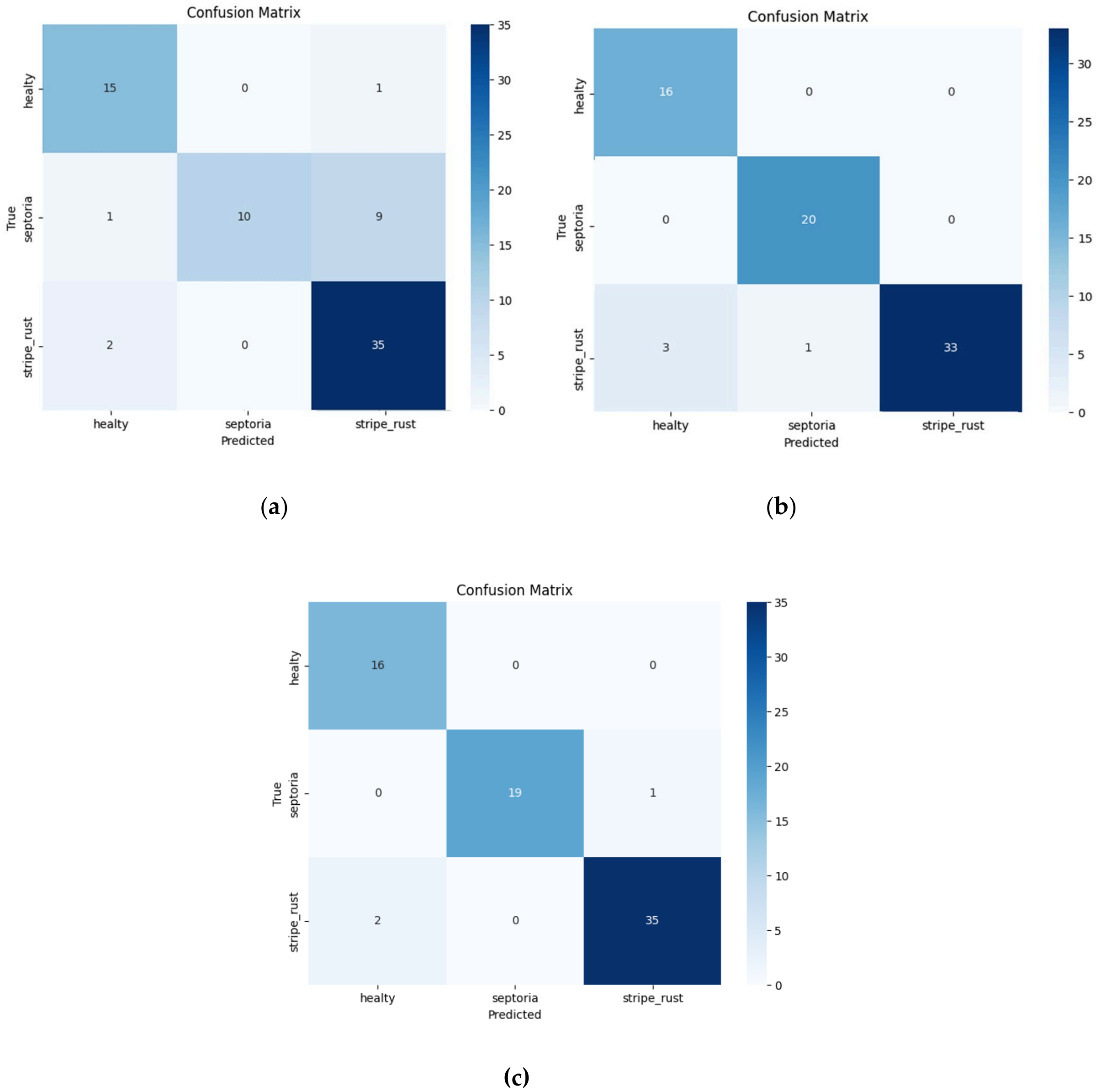
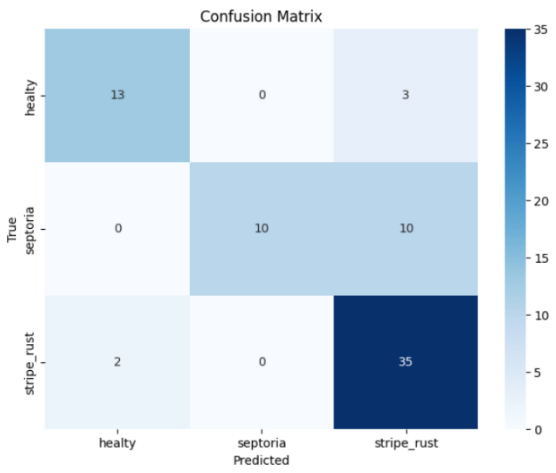
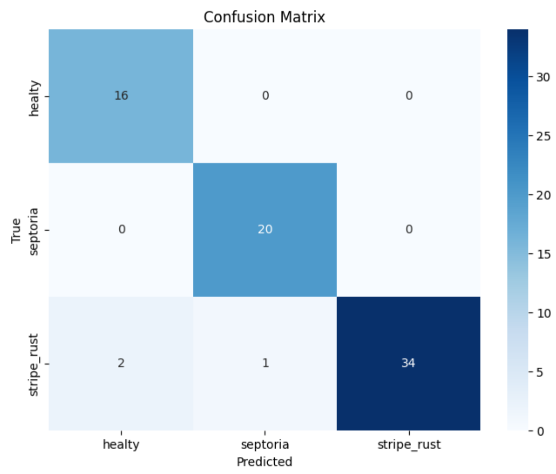


Figure 4. Confusion matrix as: (**a**) KNN with VGG-16; (**b**) MLP with VGG-16; (**c**) SVM with VGG-16

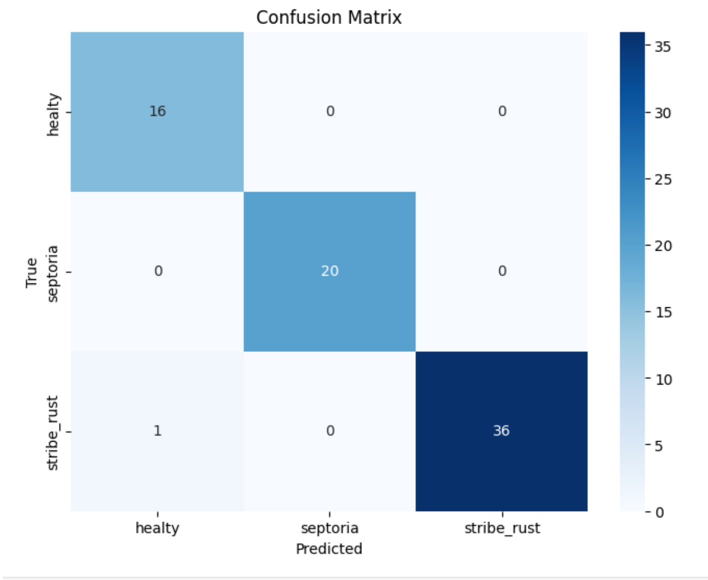
Figure 4 shows the Confusion matrices for all three classifiers (KNN, MLP, SVM) according to the features extracted with VGG-16. The number of correctly classified and misclassified instances is shown here.



(a)



(b)



(c)

Figure 5. Confusion matrix as: (**a**) KNN with VGG-19; (**b**) MLP with VGG-19; (**c**) SVM with VGG-19

Figure 5 shows the confusion matrices for the features extracted with VGG-19 for all three classifiers (KNN, MLP, SVM).

4. Discussion

In this study, two diseases seen in wheat leaves and healthy leaves were classified with image processing and machine learning. The difference of this study from other studies in the literature is that deep feature extraction and classification with machine learning algorithms KNN, MLP, SVM were performed for the first time in this study. Classification was previously performed on this dataset with pre-trained networks. In this study, differently, feature extraction was performed with pre-trained networks and classification was performed with machine learning models. Considering the classification results, high classification accuracy was obtained for this dataset. In future studies, different feature extraction methods other than VGG-16 and VGG-19 can be tested. Also, different classification models can be realized.

5. Conclusions

One of the most significant plants used as a food source worldwide is wheat. In addition to being indispensable for humans and animals, it is a plant that is easy to grow and widely cultivated all over the world (Wen et al. 2023). As in other plants, it causes significant yield and quality loss in case of disease. The most common diseases are septoria and stripe rust. Detection and diagnosis of these diseases by manual and traditional methods cause loss of time and cost. In this study, a computer-aided image processing model is proposed to classify these two diseases in wheat leaves and healthy leaves. For this purpose, a dataset of wheat leaf images was used. The backgrounds of the images were first removed. The features of the images were extracted from the pre-trained networks VGG16 and VGG19. These extracted features were classified with three different machine learning models. In the analysis, the highest classification accuracy was obtained with 98.63% when the features extracted with VGG19 were classified with SVM. It was seen that the diseases seen in wheat leaves can be successfully classified with the help of image processing and machine learning. Image processing and machine learning can be successfully used in agricultural fields. Different models can be used to improve classification performance in subsequent research. Additionally, creating various hybrid models can lead to improved categorization outcomes.

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Research Article

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Applying Various Pollution Indexes to Evaluate Heavy Metal Pollution and Contamination Levels in Soil of Karadağ Mountain from Turkey

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HIGHLIGHTS

- Heavy metal concentrations in fractions of soil and contamination.
- Pollution indices in soils formed on the volcanic material.
- Environmental risk of contamination specifiable using sequential extraction methods

Abstract

The heavy metal contents in soil fractions were determined using selective solutions and a sequential extraction procedure and then the amounts of heavy metals were calculated in these fractions of soils generated on the volcanic material of Mount Karadağ. Heavy metal status and contamination levels were determined by using pollution indices instead of comparing them with the reference rock alone. Different pollution indices were used such as Geoaccumulation index (I-geo), pollution load index (PLI), Enrichment factor (EF) and Contamination factor (CF) index. According to all indices used, there was no or very little contamination, except for RAC, and it was determined that these levels did not cause any pollution in the soil. RAC values showed a high risk especially for Cd. Although not high risk, low risk points were detected in Ni and Pb. This situation clearly reveals that in the pollution assessments, indexes that take mobile fractions into account rather than total values should be used for sensitive areas.

Keywords: Sequential extraction method; Heavy metal; Pollution indices; Karadağ

1. Introduction

Heavy metal is the term used to describe metals of the third period or higher of periodic tables, which have a physical density of more than 5g/cm^3. More than 60 metals are included in this group, such as copper, iron, cobalt, lead, chromium, nickel, cadmium and zinc. The quantity of heavy metals discharged into the environment poses major issues as a result of industrial activity's fast expansion. Environmental pollution with heavy metals may be due to both natural and man-made sources in the environment. Naturally occurring incidents such as geological weathering and volcanic eruption are the natural causes of heavy metal contamination. Heavy metal pollution of the environment is a global issue because they are difficult to extract

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from the soil. When acceptable concentration limits of heavy metals are exceeded, the majority of ecosystems are toxically affected. The heavy metals such as Cu, Pb, Cr, Fe, Zn, and Cd are often discussed in the literature regarding possible risks and occurrences in contaminated soils (Akoto et al., 2008). Because of their nature these elements are found in the earth's crust as carbonate, silicate, and sulfide, depending on stable compounds or silicates (Kahvecioğlu et al. 2004). Since the soil has a filtration feature due to its buffering capacity, it can prevent and/or delay the emergence of the effects of pollutants against the pollutants according to the water and air ecosystem. However, the issues that arise when soil deterioration results from pollution are large and complicated, and it can be difficult and costly to resolve (Kocaer and Başkaya 2003). The term "soil pollution" refers to the degradation of one or more of the physical, chemical, biological, and fertility characteristics of soils due to externally introduced or naturally occurring pollutants, as well as improper agricultural methods. Soil pollution can be named according to the type of pollutant or the deteriorated soil characteristics. Heavy metals in soils can be caused by minerals that decompose during the formation of soils (natural pollution). Heavy metal contamination can occur in soils developed on parent materials that include minerals with significant concentrations of metals (Kahvecioğlu et al. 2004). Additionally, the presence of heavy metals (artificial pollution) in the structure of compounds added to the soil for a variety of reasons may also be the cause. For example, fertilizers and pesticides that cause heavy metal accumulation, sewage waters, and treatment liquid and solid wastes are also among the heavy metal sources (Tok 1997). Natural concentrations of heavy metals are present in every soil. The chemical composition of the bedrock from which the soil is generated determines the size of a metal's background (Scazzola et al. 2003). The fundamental component of the biogeochemical system, soil, serves as both the source and the pool for a variety of contaminating species. Therefore, it is crucial in the storage and movement of pollutants (Forghania et al. 2019). Heavy metal concentrations in volcanic soils are often quite high and may exceed toxic levels. Such soils may naturally contain high levels of heavy metals due to pedo-geochemical processes (Doelsch et al. 2006). Since amorphous aluminosilicates and organo-mineral compounds produced by neoformation are abundant in soils formed on volcanic rocks, these soils have a high ability to bind heavy metals (Tanneberg et al. 2001). Heavy metals can be especially retained on aqueous oxide and oxyhydroxide surfaces of volcanic soils and subsequently absorbed due to organic complexation. Therefore, in addition to heavy metals, some trace elements nutrients for plants can also be preserved very strong and become inaccessible to plants (Tanneberg et al., 2001). Various methods can be used to evaluate the sediment enrichment with elements. The most popular ones are the pollutant load index (PLI), enrichment factor (EF), contamination factor (CF) index, and geoaccumulation index (I-geo). In addition, RAC, acid soluble fraction (F1), pollution indexes (PI), contamination degree (Cd), modified degree of pollution (mCd), can also be used to get an idea about the contamination or pollution degree. Among these indices, pollution degree (Cd), modified pollution degree (mCd), pollution load index (PLI) and pollution indices (PI) show the total effects of pollution, while others are used to reveal the individual effects of pollution elements. Determining environmental exposure hazards and comprehending the features of heavy metal contamination in soil offer crucial knowledge for both preventing soil pollution and making informed decisions about the remediation of polluted soils.

In this work, the concentrations of heavy metals in various soil fractions developed on the volcanic material of Mount Karadağ were evaluated using the sequential extraction method with selective solutions. Pollution indices were found using the results obtained and the sum of heavy metal levels in soil fractions, and the individual and cumulative effects of metals on the pollution level of the analyzed soils were emphasized.

2. **Materials and Methods**

Mount Karadağ is located in the interior belt of the Taurus Mountains, northwest of Karaman, in the semi-arid continental climate of Central Anatolia. Neogene-Quartern aged Central Anatolian volcanics in a range of volcanic mountains that run parallel to the Taurus Mountains. The yearly average temperature is 11.2 ^{o}C, and the average amount of precipitation is 340.1 mm. There is 1312.8 mm of evaporation every year. Precipitation is irregularly distributed throughout the year and mostly falls during the winter. Relative humidity is 62.5% on average. At 50 cm depths, the mean soil temperature is 13.8 °C (Anonymous 1994). Lacustrine and alluvial deposits coexist with the sedimentary formations, which are covered in an unconformable manner by this volcanism, which was active from the middle Miocene until the end of the Quaternary. Karadağ activity generated andesitic lavas of the biotite, hornblende, andesite, and hornblende andesite kinds. The topic area was examined using 1/100,000 scale soil maps (Anonymous 1992), 1/100,000 scale geological maps (Anonymous 1962), and other research in order to identify soil sample locations and collect samples. The area was then explored using topographic map sheets at a size of 1/25.000, and 15 samples were taken there in consideration of the information gathered. When selecting the sample locations, attention was given to the sort of volcanic material present in the research area. In this regard, 15 soil samples in total were gathered in Karadağ, 10 from the centrally formed volcanics in Karadağ and 5 from the andesites in Değledağ. Sample points were chosen randomly. Surface (0–20) samples were taken from 4 different locations within a 4 × 4 meter area from every sampling point. Subsequently, they were combined via subsampling and transported in plastic bags to the laboratory. A modified sequence extraction strategy was used to evaluate the amounts of Cr, Cu, Ni, Cd, Zn, and Pb (the attached forms of the heavy metals) in different fractions of soil samples. The total concentration of heavy metals was calculated as the sum of the heavy metal concentrations in each of the fractions. Many studies have described in detail the modified BCR sequential extraction method (Usero et al. 1998; Rauret et al. 1999; Ololade 2009). Metal analysis procedures were applied to the acid-extractable fraction (depending on the exchangeable and carbonate fractions), the easily reducible fraction (depending on the Fe / Mn oxide fraction), the oxidizable fraction (depending on the organic matter fraction), and the residual fraction using the BCR sequential extraction method. The pollution indices were calculated using the sum of heavy metal contents. Following air drying, the soil samples taken from the site were passed through a 2 mm sieve. A mortar grinder was used for blending soil samples homogenously before they were sieved through a 0.5 mm mesh. These samples were subjected to elemental analysis, organic matter analysis and calcium carbonate analysis. The hydrometer technique was used to determine the particle size distribution (Bouyoucos 1951). Before this process, carbonates and organic matter and salts were eliminated, and the samples were shaken in 10 milliliters of 40% sodium hexametaphosphate (Calgon) to disperse them (Gee and Bauder, 1986). The techniques of the Soil Research Laboratory (2004) were used to determine the (electrical conductivity) values of saturated soil samples. A Scheibler calsimeter (Soil Survey Manual 1993) was used to determine the $CaCO_3$ content. By titrating an acid-dichromate digestion with Fe_2SO_4, the amount of organic matter in the soil was determined (Walkley, Black, C.A. 1934). Analyses of Cd, Cu, Cr, Ni, Pb, and Zn in soil samples were carried out in an air-acetylene flame using an Agilent 5110 ICP-OES spectrometer. Metals are operated within their recommended ranges by the manufacturer. To evaluate the accuracy of the approach, an examination of the BCR-701 certified reference soil was examined and the findings were compared to the certified element concentration of the BCR. In the acid and water-soluble fraction, Oxidisable fraction, and reducible fraction, the heavy metal recovery rates in the standard reference material were found to range from 89% to 122.7%, 92.1% to 114.7%, and 71.6% to 98.9%, respectively. These rates were all regarded as acceptable. Standard items of STD DS 11 and STD OREAS 262 were also used to validate the residual fraction. Heavy metal recovery rates in the residual portion of the standard reference material varied from 91.1% to 119.4%. Each extraction phase in the BCR sequential extraction process, including the residual phase, has its own limit of detection (DL) established. Three replication samples from each stage were analyzed, and ten measurements were made. In the DL computation, the 3s/b equation has been taken into account. Where is the standard deviation of the absorbance of the blank samples and is the slope of the calibration graph for each element? DL limits ($g.mL^{-1}$) were found between 0.001-0.098 in the acid and water-soluble fraction, 0.002-0.70 in the oxidisable fraction, and 0.002-0.6 in the reducible fraction.

3. **Results and Discussion**

3.1. Shift in Soil Conditions

Values and descriptive statistics for certain physicochemical properties of the investigated soils are provided in Table 1. The average soil pH was 6.94, ranging from slight acidic to slightly alkaline. Between 72.5-261μS/cm is the range of electrical conductivity values, and no issues with agricultural salinity were noted. The mean percentage of organic matter in soil is 2.77%, with a range of 1.30 to 5.54%; $CaCO_3$ concentration ranges from 0.43 to 14.43 percent, with an average of 2.44%, and is characterized as mildly calcareous. The percentage of sand varied from 43.9 to 70.2%, the amount of silt from 6.3 to 30.0%, and the fraction of clay from 22.4 to 49.9%. These findings demonstrate that soil properties differ between sample sites. The text continues here.

Table 1. Physical and chemical characteristics of soil samples found in the study area

Example Number	**pH (1/2.5)**	**EC (μS/cm)**	**Organic Matter (%)**	**$CaCO_3$ (%)**	**Particle Size Distribution**		
					Clay (%)	**Silt (%)**	**Sand (%)**
1	7.53	238.3	4.04	0.62	26.1	25.0	48.9
2	6.71	72.5	1.80	0.47	24.9	8.7	66.4
3	6.60	81.7	1.87	0.43	23.6	6.3	70.2
4	6.70	99.0	1.77	0.58	22.4	7.5	70.2
5	6.78	182.2	2.80	0.72	37.4	18.8	43.9
6	7.10	138.3	1.41	1.75	37.4	16.3	46.4
7	7.30	215.5	4.19	2.34	31.1	30.0	38.9
8	6.94	209.1	4.29	0.74	49.9	27.5	22.7
9	6.62	261.0	5.54	0.58	31.1	28.8	40.2
10	6.55	197.4	4.72	0.74	26.1	18.8	55.2
11	6.65	80.7	1.30	0.66	34.9	10.0	55.2
12	7.19	128.1	2.06	10.92	27.4	17.5	55.2
13	7.27	131.9	1.41	14.43	38.6	15.0	46.4
14	7.11	121.9	2.16	0.82	34.9	16.3	48.9
15	6.97	104.6	2.19	0.82	28.6	17.5	53.9
Maximum	**7.53**	**261.0**	**5.54**	**14.43**	**49.9**	**30.0**	**70.2**
Minimum	**6.55**	**72.5**	**1.30**	**0.43**	**22.4**	**6.3**	**43.9**
Mean	**6.94**	**150.8**	**2.77**	**2.44**	**31.6**	**17.6**	**50.8**
ST	**0.30**	**61.6**	**1.39**	**4.24**	**7.3**	**7.6**	**12.5**

3.2. Heavy Metal Contents Detected by Sequential Extraction

Heavy metals can be found in soils in many different kinds of geochemical forms, such as changeable structure caused by iron and manganese oxides or connected with organic matter residual forms due to many physico-chemical and biological processes. Because of this heavy metals' mobility and bioavailability in soil are also affected by their geochemical forms, not just their total concentration (Bilgin et al. 2020). That is why it's critical to use a variety of extraction procedures to ascertain the percentages of mobilizable trace elements. Sequential extraction techniques (SEPs) have been developed to identify different geochemical forms of trace metals because of trace metal mobility depends on the interaction between trace metals and soil (Doelsch et al. 2008). The European Community Reference Bureau (BCR) has started utilizing a standard SEP to evaluate the results of different SEPs (Rauret et al. 1999). Table 2 displays the average distributions of heavy metals by BCR sequential extraction technique. In the study's S1 phase (exchangeable, acid and water soluble fraction) Cd was distributed between 0.032-0.106, Cr between 0.034-0.160, Cu between 0.084-1.160, Ni between 0.509-2.646, Pb between 0-0.393 and Zn between 0.380-2.724. In the S2 phase (Reducible fraction), these values varied from 0.004-0.1036 for Cd, 0.0336-1.1655 for Cr, 1.184-4.697 for Cu, 1.038-6.916 for Ni, 3.317-9.037 for Pb, and 3.414-15.161 for Zn. In the S3 (Oxidisable fraction) stage, it varied from 0.000 to 0.1069 for Cd, 1.48 to 14.939 for Cr, 2.690 to 4.720 for Cu, 1.665 to 6.752 for Ni, 0.037 to 1.875 for Pb, and 2.896 to 4.577 for Zn. The metal contents distribution in the residual portion was as follows: 1.28 to 5.70 for Pb, 17.70 to 40.0 for Zn, 10.66 to 28.70 for Cr, 7.93 to 17.82 for Cu, 11.40 to 35.30 for Ni, and 0.0 to 0.020 for Cd.

Table 2. Karadağ Soil Samples for Heavy Metals Distribution using BCR Sequential Extraction Scheme (µg/g dry weight mean ± St Dev*) n is fifteen.

	Exchangeable, acid-and water soluble (S1)		Reducible (S2)		Oxidisable (S3)		Residual (S4)		Total Σ (S1 + S2 + S3 + S4)	
Metal	**Average ±St Dev.**	**Rate (%)**	**Average ±St Dev.**	**Rate (%)**	**Average ±St Dev.**	**Rate (%)**	**Average ±St Dev.**	**Rate (%)**	**Average ±St Dev.**	**Rate (%)**
Cd	0.070±0.021	45.8	0.034±0.030	22.2	0.029±0.026	19.0	0.02±0.008	13.1	0.153**±0.02**	100
Cr	0.093±0.040	0.4	0.918±0.364	3.9	2.840±0.954	12.1	19.71±5.861	83.7	23.561**±9.28**	100
Cu	0.286±0.264	1.4	3.040±1.037	14.6	3.656±0.568	17.6	13.82±2.838	66.4	20.802**±5.93**	100
Ni	1.412±0.743	5.1	3.602±1.980	13.1	3.157±1.399	11.4	19.41±7.042	70.4	27.581**±8.40**	100
Pb	0.107±0.128	1.2	5.465±1.534	60.1	0.578±0.448	6.4	2.94±1.081	32.3	9.09**±2.46**	100
Zn	1.074±0.771	2.8	5.950±2.769	15.6	3.385±0.449	8.9	27.81±6.009	72.8	38.219**±12.33**	100

3.3. Evaluation of Heavy Metal Contamination Level

Due to its intricate structure, soil, which is a dynamic natural resource for human life, is a primary recipient of persistent pollutants, including heavy metals. All soils have natural concentrations of heavy metals called background. The quantity of the background of a metal depends on the mineral composition of the bedrock that developed the soil (Scazzola et al. 2003). Changes in heavy metal levels in soil vary according to the amount in the bedrock, enrichment, or leaching status. The individually total quantity of heavy metals in the soil is inadequate to accurately describe their efficacy and level of contamination. Therefore, when evaluating heavy metal pollution and learning how it affects living things, evaluating the impacts of many heavy metals as well as the effect of one heavy metal alone produces significantly superior findings. Numerous soil pollution quality indices suggested by different researchers have been successfully used in the evaluation of heavy metal pollution in soils. The heavy metal concentrations in various fractions of soils in this investigation as well as total heavy metal amounts were evaluated with the following heavy metal pollution indices and both the individual and cumulative impacts of metals on pollution were identified. These results led to the determination of the levels of heavy metal contamination in the soils of the research region that were developed on the volcanic material in the study area. The pollution indices showing the individual and cumulative effects of heavy metals in soil samples collected from the research region are shown in Table 3 and the categories and descriptions of the employed indices are provided in Table 4. The Enrichment Factor (EF) is a method used in the evaluation of metal pollution due to human-induced contamination and pollutants. The enrichment of an element is commonly defined as a rise in the concentration of that element along the soil profile from the source material to the surface. The following formula was used to obtain the enrichment factor, based on Hasan et al. (2013).

$$EF = (CX/C_{Fe})\ soil/(CX/C_{Fe})\ referans$$

Where,

(CX/C_{Fe}) soil: The metal content ratio investigated for the Fe content in the soil sample, (CX/C_{Fe}) referans the proportion between the Fe concentration and the metal concentration that was examined in the reference rock.

The reference rock metal concentration is the quantity of elements in the pertinent rock in the earth's crust (Taylor and McLennan 1985). The EF in Karadağ varied from 0.10-0.34 for Cd, 0.13-0.34 for Cr, 0.47-0.77 for Cu, 0.34-1.11 for Ni, 0.13-0.39 for Pb, and 0.27-0.54 for Zn, as seen in Table 3. These results suggest that there is no enrichment in the soils of Karadağ when the calculation is conducted using the contents of reference rocks. Except for two sample points, Ni's EF was always less than 1. The EF value is below 2 for these two sample locations and exhibits minimal enrichment.

Table 3. Pollution Index Values for the Research Area's Soils

Sample No	EF						Igeo						Multi Metal	
	Cd	Cr	Cu	Ni	Pb	Zn	Cd	Cr	Cu	Ni	Pb	Zn	PLI	Cd
1	0.24	0.20	0.72	0.52	0.23	0.54	-2.25	-2.52	-0.70	-1.15	-2.35	-1.11	0.47	3.17
2	0.16	0.13	0.47	0.34	0.17	0.30	-2.82	-3.22	-1.32	-1.79	-2.77	-1.96	0.30	2.01
3	0.12	0.14	0.60	0.44	0.16	0.29	-3.26	-3.04	-0.95	-1.40	-2.85	-1.98	0.32	2.27
4	0.23	0.13	0.62	0.41	0.13	0.27	-2.35	-3.21	-0.90	-1.52	-3.19	-2.12	0.32	2.29
5	0.22	0.25	0.77	0.68	0.25	0.39	-2.41	-2.23	-0.59	-0.78	-2.22	-1.58	0.48	3.29
6	0.10	0.22	0.66	0.58	0.24	0.38	-3.57	-2.38	-0.82	-0.99	-2.30	-1.62	0.39	2.81
7	0.34	0.33	0.64	1.11	0.25	0.47	-1.79	-1.80	-0.86	-0.07	-2.20	-1.32	0.59	4.05
8	0.24	0.34	0.73	0.82	0.39	0.52	-2.25	-1.76	-0.67	-0.51	-1.57	-1.18	0.60	3.93
9	0.14	0.20	0.54	0.50	0.27	0.43	-3.07	-2.52	-1.10	-1.21	-2.12	-1.42	0.40	2.69
10	0.20	0.27	0.63	0.54	0.19	0.40	-2.52	-2.12	-0.87	-1.11	-2.60	-1.54	0.43	2.88
11	0.25	0.24	0.62	0.59	0.19	0.36	-2.24	-2.29	-0.90	-0.99	-2.60	-1.70	0.43	2.89
12	0.23	0.29	0.58	1.09	0.19	0.39	-2.34	-1.98	-1.00	-0.10	-2.65	-1.56	0.49	3.57
13	0.14	0.29	0.66	0.70	0.19	0.41	-3.07	-2.02	-0.82	-0.73	-2.63	-1.49	0.43	3.08
14	0.16	0.25	0.54	0.51	0.17	0.31	-2.85	-2.24	-1.10	-1.19	-2.79	-1.92	0.37	2.49
15	0.25	0.21	0.72	0.47	0.21	0.35	-2.22	-2.50	-0.70	-1.30	-2.46	-1.71	0.43	2.85
Sample No	**Cf**						**RAC (%)**						**Multi Metal**	
	Cd	**Cr**	**Cu**	**Ni**	**Pb**	**Zn**	**Cd**	**Cr**	**Cu**	**Ni**	**Pb**	**Zn**	**MCd**	**PI**
1	0.31	0.26	0.93	0.67	0.30	0.69	47.13	0.27	1.09	3.67	3.12	3.67	0.53	0.36
2	0.21	0.16	0.60	0.43	0.22	0.39	43.75	0.94	7.57	4.67	0.31	9.23	0.34	0.23
3	0.16	0.18	0.78	0.57	0.21	0.38	65.85	0.78	1.76	4.03	1.51	3.78	0.38	0.27
4	0.29	0.16	0.80	0.52	0.16	0.34	54.09	0.47	2.20	5.19	3.13	3.60	0.38	0.26
5	0.28	0.32	0.99	0.88	0.32	0.50	49.29	0.26	0.87	8.75	0.87	1.69	0.55	0.40
6	0.13	0.29	0.85	0.75	0.31	0.49	79.74	0.59	0.57	6.56	0.00	1.08	0.47	0.34
7	0.43	0.43	0.83	1.43	0.33	0.60	46.33	0.22	0.82	1.59	3.67	1.08	0.68	0.53
8	0.32	0.44	0.94	1.05	0.51	0.66	37.04	0.45	0.35	7.23	0.00	1.76	0.65	0.48
9	0.18	0.26	0.70	0.65	0.35	0.56	33.97	0.35	0.63	4.06	0.00	6.03	0.45	0.32
10	0.26	0.34	0.82	0.70	0.25	0.52	49.86	0.22	0.94	4.26	0.00	3.62	0.48	0.34
11	0.32	0.31	0.80	0.75	0.25	0.46	48.19	0.58	0.77	9.77	3.65	1.08	0.48	0.35
12	0.30	0.38	0.75	1.40	0.24	0.51	63.84	0.25	1.50	3.75	1.46	1.28	0.59	0.48
13	0.18	0.37	0.85	0.90	0.24	0.53	91.45	0.12	1.85	1.63	0.00	1.19	0.51	0.38
14	0.21	0.32	0.70	0.66	0.22	0.40	40.74	0.33	0.91	6.95	1.18	1.84	0.42	0.30
15	0.32	0.27	0.92	0.61	0.27	0.46	46.99	0.77	0.73	8.35	0.37	2.88	0.47	0.33

The Geoaccumulation Index, or Igeo, was created by Muller in 1969 and is used to determine the degree of pollution present in a sediment sample as well as to help identify and categorize it into different pollution classes. The Geoaccumulation Index, or Igeo, was created by Muller in 1969 and is used to determine the degree of pollution present in a sediment sample as well as to help identify and categorize it into different pollution classes.

$$\text{Igeo} = \log 2\left(\frac{\text{Cn}}{1.5\text{xBn}}\right)$$

Where,

The measured concentration of the heavy metal in the soil sample is denoted by Cn, the background matrix correction factor resulting from lithogenic effects is 1.5, and Bn is the geochemical background (reference) value in the earth's crust average of n elements. For all metals in Karadağ (Igeo), the quantities less than 0 were found at all sample points, as demonstrated by the outcomes listed in Table 3. Considering these results, it was found that the Igeo assessment was uncontaminated. Although the terms contamination and pollution are often used interchangeably, it should be kept in mind that these terms do not mean exactly the same. Accordingly, the term "contamination refers" to the existence of an unnatural material at quantities that are higher than background levels. Pollution, on the other hand, is a contamination that causes or results in adverse biological effects. This difference makes it clear that pollution is a significant form of contamination.

Table 4. Categories and Qualification for the Used Indexes

EF	**Qualification of Sediment**	**Igeo**	**Qualification of Sediment**	**PLI**	**Qualification of Sediment**	**RAC**	**Qualification of Sediment**
<1	No Enrichment	≤ 0	Unpolluted	PLI< 0	Uncontaminated	<%1	No Risk For The Environment
<2	Minimal Enrichment	0<Igeo<1	Slightly Polluted	0 <PLI< 1	Uncontaminated to Moderately Contaminated	% 1-10	Low Risk
2-5	Moderate Enrichment	1<Igeo<2	Moderately Polluted	1 <PLI< 2	Moderately Contaminated	% 11-30	Moderately Risk
5-20	Considerable Degree of Enrichment	2<Igeo<3	From Moderately Polluted to Strongly Polluted	2 <PLI< 3	Moderately to Highly Contaminated	% 31-50	High Degree Risk
20-40	Very High Enrichment	3<Igeo<4	Strongly Polluted	3 <PLI< 4	Highly Contaminated	>%50	Very High Risk
>40	Extremely High Enrichment	4<Igeo<5	From Strongly Polluted to Extremely Polluted	4 <PLI< 5	Highly to Very Highly Contaminated	-	-
		5≤Igeo	Extremely Polluted	PLI>5	Very Highly Contaminated		
Cf	**Qualification of Sediment**	**Cd**	**Qualification of Sediment**	**mCd**	**Qualification of Sediment**	**PI**	**Qualification of Sediment**
Cf < 1	Low Contamination	Cd< 10	Low Degree of Pollution	mCd< 1	Nil to a Very Low Degree of Pollution	PI < 1	Unpolluted
1 < Cf <3	Moderate Contamination	10<Cd< 20	Moderate Degree of Pollution	1 <mCd< 3	Low Degree of Pollution	1 <PLI< 3	Low Degree of Pollution
3< Cf< 6	Considerable Contamination	20 <Cd< 40	Considerable Degree of Pollution	3 <mCd< 6	Considerable Degree of Pollution	3 <PLI< 5	Moderate Degree of Pollution
Cf > 6	Very High	Cd>40	High Degree of Pollution	mCd> 6	High Degree of Pollution	PLI >5	High Degree of Pollution

Pollution is not always the result of contamination; rather, pollution is the result of concentration levels that have detrimental impacts on organisms that might be deemed substantial. Pollution factor (Cf) is also an indicator widely used by many researchers to evaluate the anthropogenic effects of heavy metals in sediment samples and to reveal the extent of environmental pollution. "Average threshold values" or "mean crustal values" are used to calculate the pollution factor. Because of this, calculations were made of the soil pollution factors in the research region.

The ratio of the metal concentration at each sample location to the quantity of that metal in the earth's crust was used to create the equation below, which was used to find the pollution factor (Cf) (Hakanson, 1980). $\mathrm{Cf} = \mathrm{Cmetal}/\mathrm{Co}$

Where:

Cmetal: The amount of metal present in the soil sample; Co: The amount of metal present in the crust of the earth. The calculated Cf value was analyzed in 4 different pollution categories. According to Table 3 in Karadağ, Cf varied from 0.13 to 0.43 for Cd, 0.16 to 0.44 for Cr, 0.6 to 0.99 for Cu, 0.43 to 1.43 for Ni, 0.16 to 0.51 for Pb, and 0.34-0.69 for Zn. Even though there is a weak contamination at certain spots, it has been established that there is no pollution when all values are considered.

The term "RAC" refers to the acid and water soluble fraction (S1), which is used to assess the environmental dangers associated with heavy metals. (Li et al. 2013). The given formula below is used to compute RAC.

$$\mathrm{RAC}(\%) = \left(\frac{\mathrm{S1}}{\mathrm{S1} + \mathrm{S2} + \mathrm{S3} + \mathrm{S4}}\right) \mathrm{x100}$$

The increase in human activity is often what causes the water and acid soluble fraction (RAC). This fraction of heavy metals contains the more bioavailable and loosely bound portion (Jin et al., 2012). RAC in Karadağ; It varied between 33.97-91.45% for Cd, 0.12-0.94% for Cr, 0.35-7.57% for Cu, 1.59-9.77% for Ni, 0.00-3.67% for

Pb, and 1.08-9.23% for Zn. Although there is no pollution in the current situation, the pollution potential of these metals, especially Cd, goes from intermediate to high risky. Therefore, at higher rates of anthropogenic contamination, care should be taken as these metals have a high risk of mixing with groundwater and polluting plants and other living things. In the evaluations using other indices, there was no significant pollution or contamination in the soils, but RAC values were found to indicate a high risk, particularly for Cd. Although there is currently no high risk, sample points in the low risk group for Ni and Pb were found in the RAC evaluation. When the other soluble components are taken into account, notably for Cd and Pb the risk class increases even more especially for Cd and Pb. This circumstance demonstrates unequivocally that in pollution evaluations, indexes that take mobile fractions into account rather than total values should be used for sensitive areas.

The pollutant load index (PLI) was developed to compare the pollution status of different locations, to determine the extent of pollution and variation across different sampling stations. It can be defined as an integrated index since it collects all the heavy metals studied in a single index. Since all the metals under consideration are handled in a single index, they are frequently used to compare the pollution levels in various places. Each metal's pollution factors (Cf) are determined to produce the index. The pollutant load index (PLI) was created using the following formula (Tomlinson et al. 1980).

$$PLI= (Cf1 * Cf2 * Cf3 * \ldots.. * Cfn)1/n$$

$$Cf= Cmetal / Co$$

Where:

Cmetal: The amount of metal in the sediment sample
Co: The metal's fundamental (background) value
Cf: Pollution coefficient, n: Metal count

The PLI in Karadağ ranged from 0.30 to 0.60, with an average of 0.43, as shown in Table 3. The PLI ranges from 0 to 1, and there is no discernible contamination or pollution at any of the sample locations.

Hakanson (1980) recommended utilizing a diagnostic measure termed the degree of contamination (Cd) to streamline contamination control. The total of all the pollution elements within a certain basin is its Pollution Degree (Cd). Cd has been calculated by adding up Cf for every sample.

$$\mathrm{Cd} = \sum_{i=1}^{i=n} \mathrm{Cf}$$

When the study area soils are evaluated in terms of Cd, all values in Karadağ are less than 10 and do not indicate any pollution (Table 3). The modified degree of contamination (mCd) approach may also be used to approximation the precise level of contamination.

For this objective, the following equation was used to obtain the modified contamination degree (mCd) (Abrahim and Parker, 2008).

$$\mathrm{mCd} = \frac{\sum_{i=1}^{i=n} \mathrm{Cf}}{\mathrm{n}}$$

The mCd values of the soils and their reference ranges are presented in Table 3 and Table 4. The average mCd value in Karadağ varied from 0.34 to 0.68, with an average of 0.49. The results obtained at all points in Montenegro are less than 1 and do not indicate any pollution in terms of the total effect of metal pollution.

Pollution indexes (PI) of heavy metals in soils were also determined using the soil environmental quality standards of Canadian soil quality guidelines for the protection of the environment and human health. PI was calculated using the following formula.

$$PI = Ci/Si$$

PI values varied between 0.23-0.53 in Karadağ. PI values calculated for each element, taking into account the maximum allowable metal content for human health, showed that there was no pollution that would pose any health risk.

4. Conclusions

The contents of Cd, Cr, Cu, Ni, Pb, and Zn in mobile and residual fractions of soils obtained from Karadağ volcanic rocks were evaluated in this work using the BCR sequential extraction procedure, and the mobility of each metal was revealed based on fractions. The levels of heavy metal contamination and pollution in the area, both in terms of individual and cumulative impacts, have also been determined using several pollution indices and additionally to the concentrations of heavy metals in the area's mobile and immobile fractions. None of the used indices, with the exception of RAC, indicated any pollution in the soils investigated. It was determined that these levels obtained did not cause any pollution in the soil. While assessments using other indices revealed no appreciable pollution or contamination in the soils, RAC values indicated a high risk, particularly for Cd. Some sample spots for Ni and Pb were found in the low-risk group, although not being high risk. According to RAC values although not high-risk for Ni and Pb some sampling spots were found in the low-risk group. With the help of this study, it was found that the BCR sequential extraction process may offer useful data for a range of management and organization applications (fertilization, spraying, etc.) in agricultural fields. It has been shown that using sequential extraction methods and various pollution indicators, the metal availability across different soil components, the possible impacts on the environment, and the risk of contamination may all be assessed more efficiently. The finding shows that assessments using pollution indices can serve to design and undertake effective strategies and measures to prevent further degradation of the soil environment in future farmland and regions with prospective pollution issues.

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Research Article

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Effects of Autochthonous Starter Cultures on the Behavior of *Staphylococcus aureus* during the Production of a Semi-Dry Fermented Sausage

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HIGHLIGHTS

- A rapid pH drop during fermentation is of great importance for the control of *Staphylococcus aureus*.
- *Lactilactobacillus sakei* S15 was more effective on *S.aureus*.
- Enterotoxine could not be detected even when no starter culture was used.
- *L.sakei* S15 and *Lactiplantibacillus plantarum* S91 decreased the pH below 5,3 after 24 h of fermentation.

Abstract

Staphylococcus aureus can grow and produce enterotoxin during the production of fermented sausages, especially in the early stage of the fermentation. Furthermore, staphylococcal enterotoxins are heat-stable. Therefore, inhibiting the growth of this pathogen during production is of great importance for food safety. The study was carried out to determine the effects of autochthonous lactic acid bacteria (LAB) strains (*Lactiplantibacillus plantarum* S91, *Latilactobacillus sakei* S15 and *Pediococcus acidilactici* S147b) on the behavior of *S. aureus* in heat-treated sucuk (HTS) (raw fermented cooked and dried), a type of semi-dry fermented sausage. The HTS batters were inoculated with *S. aureus* ATCC 51740 (SEB) at 10^5 CFU/g level. In groups containing *L. sakei* S15, pH decreased faster in the first 24 h of fermentation (22 °C) than in other groups. After 48 h, pH dropped below 5.0 in all groups with autochthonous strains, while it was still above 5.5 in groups without autochthonous strains. Therefore, while the number of *S. aureus* increased during fermentation in the sausage group without autochthonous strains, there was no significant change in the number in the presence of autochthonous strains. The heat treatment (core temperature; 68 °C) caused significant reductions in *S. aureus*, LAB and *Micrococcus/Staphylococcus* (< 2 log CFU/g). At the end of drying (18 °C), the a_w value varied between 0.927 and 0.935. Staphylococcal enterotoxin was not detected in all groups. In conclusion, the rapid decrease in pH during the early stage of fermentation is an important hurdle effect in the controlling the growth of *S. aureus*.

Keywords: *Staphylococcus aureus*; Fermented sausage; Autochthonous strains; Heat treated sucuk; Staphylococcal enterotoxin

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1. Introduction

Foodborne pathogens have become an important social problem for consumers. They have also received much attention from consumers and food safety authorities around the world due to frequent outbreaks of microbial infections and intoxication (Gao et al. 2019). *Staphylococcus aureus* is an important pathogen for humans and animals. In addition to staphylococcal infections, *S. aureus* also causes staphylococcal intoxications through the enterotoxins (Titouche et al. 2020). The optimum growth temperature of *S. aureus* ranges from 30 to 37 °C, and it can grow in a wide range of temperature (7 to 48.5 °C) (Kadariya et al. 2014). In addition, this bacterium can show optimum growth between pH 6.0 and 7.0. *S. aureus* can tolerate salt and nitrite. However, this pathogen is a poor competitor under anaerobic conditions, at low pH and low temperatures (Holck et al. 2017; Lücke 1998). Another characteristic of this pathogen is sensitivity to heat treatment. The D value is approximately 1 min at 65 °C (Lücke and Troeger 2007). *S. aureus* produces a range of staphylococcal enterotoxins (SEs) which are a major cause of foodborne intoxications. SEs are resistant to freezing, drying, heat treatment, and low pH (Antoine Hennekinne et al. 2012; Loir et al. 2003). They are also resistant to proteolytic enzymes (Antoine Hennekinne et al. 2012). In addition, enterotoxins can form over a wide range of temperatures (10 - 48 °C), a_w (0.87 - 0.99), pH (4 - 10) and salt (1.7 - 17%). The optimum conditions for enterotoxin production in terms of temperature, a_w, pH and salt level are 37 °C, 0.98, 6-7 and 3.7 %, respectively (Bang et al. 2008).

The decreases in pH and a_w values fermentation and drying in fermented sausages are of great importance for product safety. These sausages play an important role in staphylococcal food poisoning (Ananou et al. 2005; Ferreira et al. 2006). The main reason for this is that the pH and a_w values of sausage batches are suitable for the growth of *S. aureus* (Hampikyan 2009; Lücke 1998; Sameshima et al. 1998). In the first days of fermentation, a critical stage for pathogenic microorganisms, *S. aureus* can grow well and produce enterotoxins in fermented sausages (Gonzalez-Fandos et al. 1999; Paramithiotis and Drosinos 2017; Rajkovic et al. 2017). All these points show that the growth of *S. aureus* during the early stages of fermentation is very important for microbiological stability in fermented sausages.

Heat-treated sucuk (HTS), a type of semi-dry fermented beef sausage, is made from beef or poultry. There are three consecutive processing stages in the production of this product: fermentation, heat treatment and drying. Considering that heat treatment has a significant contribution to product safety, the production of this product is increasing day by day (Kaban and Bayrak 2015). However, there is no information on the behavior of *S. aureus* in HTS. Therefore, the aim of this work was the evaluate the influence of autochthonous strains (*Lactiplantibacillus plantarum* S91, *Latilactobacillus sakei* S15 or *Pediococcus acidilactici* S147b) and their mixture on the behavior of *S. aureus* during processing of HTS, as well as determination of a_w, pH and numbers of *Micrococcus*/*Staphylococcus* and lactic acid bacteria (LAB). The study also examined the presence of enterotoxins in final products.

2. Materials and Methods

2.1. Material

Latilactobacillus sakei S15 (KR025387), *Lactiplantibacillus plantarum* S91 (KT327838), and *Pediococcus acidilactici* S147b (KT275957) strains (Kaya et al. 2017) were added to batters as starter cultures. *Staphylococcus aureus* ATCC 51,740 (SEB) strain was used for HTS batter contamination. Beef and beef fat were used in the production of the HTS batters.

2.2. Sausage Production

In the production of HTS, per kg meat and fat (80 % lean beef and 20 % meat fat) was used: 20 g salt, 4 g sucrose, 5 g black pepper, 2.5 g allspice, 10 g garlic, 9 g cumin and 7 g red pepper. Sodium nitrite (150 mg/kg) was used as curing agent. Three independent batches were prepared for each treatment: A: *S.aureus* and starter culture not inoculated, B: *S.aureus*, C: *S.aureus* / *L. plantarum*, D: *S. aureus* / *L. sakei*, E: *S. aureus* / *P. acidilactici*, F: *S. aureus* / *L. plantarum* / *L. sakei* / *P. acidilactici*. Thus, a total of eighteen batches were prepared. *S. aureus*

ATCC 51,740 was inoculated at 10^5 CFU/g, the autochthonous strains were added at 10^7 CFU/g into batches. The experiment was replicated three times. Thus, eighteen batches were prepared.

The HTS batters were prepareted in a small scale cutting machine (MADO, MTK 662, Germany). The batters prepared were filled into collagen casing (38 mm, Naturin Darm, Germany) using filling machine (MADO, MTK 591, Schwarzwald). After filling, the HTS samples were transferred to a climate chamber (Reich, Germany). After fermentation (relative humidity; 92 ± 2 %, temperature; 22 ± 1 °C, fermentation duratation; 24, 48 or 72 h.) the samples were subjected to the heat treatment (core temperature; 68 °C) in a cooking chamber (Mauting, Czech Republic). After this process, the samples were again transferred to the climate chamber for drying and dried (relative humidity; 84 ± 2 %, temperature; 18 ± 1 °C).

2.3. Sampling

The sampling was carried out during fermentation times (0, 24, 48 and 72 h). Sampling was also done after heat treatment and drying processes. The samples were subjected to the following microbiological and physicochemical analyzes.

2.4. pH and a_w Analysis

For the analyse pH value, 10 g of the sample was homogenized with 100 mL of distilled water for 1 min. The pH value was measured using a pH-meter (Mettler Toledo, Switzerland). Buffer solutions (pH 4 and 7) were used to calibrate the pH meter.

To determine the water activity (a_w) value the water activity device was used (Novasina, Model TH 500, Switzerland).

2.5. Microbiological Analysis

The spread plate method was used for the bacterial enumerations. Baird-Parker Agar (Merck, Germany) plates were used for the enumeration of *S. aureus*. After incubation (48 h, 37 °C), typical black colonies were subjected to the coagulase test. De Man Rogosa Sharpe Agar (Merck, Germany) and Mannitol Salt Phenol Red Agar (Merck, Germany) were used for the enumeration of the LAB and *Micrococcus*/*Staphylococcus*, respectively. MRS plates were incubated at 30 °C for 48 h under anaerobic jar (Anaerocult A, Merck, Germany). MSA plates were incubated at 30 °C for 48 h.

2.6. Enterotoxin Analysis

The presence of enterotoxins was determined using the VIDAS Staph enterotoxin II (Biomerieux, France) enzyme-linked fluorescent immunoassay (AOAC 2007).

2.7. Statistical Analysis

The autochthonous LAB and the processing stages were considered as factors. Three batches (replicates) of sausage were produced independently for each group. The autochthonous LAB was evaluated as fixed effect and three replications as random effect. All data were subjected to statistical analysis (Two-way ANOVA) using SPSS (Chicago, USA).

3. Results

3.1. pH and a_w

The changes in the pH of the HTS during the production are shown in Figure 1. The pH value was affected by the fermentation time (0, 24, 48 and 72h) ($p < 0.01$). No significant change in pH value was observed after 24 h of fermentation in A (*Staphylococcus aureus* and starter culture not inoculated) and B (*S. aureus* inoculated) groups. However, there was a slight decrease in pH value after 48 h of fermentation in these groups. As can be seen from Figure 1, a wide variation in pH value was observed. This result is thought to be due to the diversity of the microbiota of the raw material. To put it more clearly, a decrease in pH was observed depending on the spontaneous flora. A similar trend was observed after 72 h. The use autochthonous starter culture (mixed or mono) caused a significant decrease in pH value throughout fermentation. Lactic acid formation is the main reason for pH decrease. During the fermentation, the autochthonous LAB exhibited a good growth produced lactic acid, which reduced the pH value of the sausages. The pH decrease in the first 24 h of fermentation is important for the inhibition of *S. aureus*. After 24 h of fermentation, the pH in group E with *Pediococcus acidilactici* S147b did not fall below 5.3. The result indicated that, *Latilactobacillus sakei* S15 and *Lactiplantibacillus plantarum* S91 showed better growth at applied fermentation temperature (22 °C) than *P. acidilactici* S147b. However, *L. sakei* S15 decreased pH more than *L. plantarum* S91. Lücke (1998) and Kaban et al. (2012) also reported that *L. sakei* is more effective than other LAB species in fermented sausages at initial fermentation temperature of 20 - 22 °C.

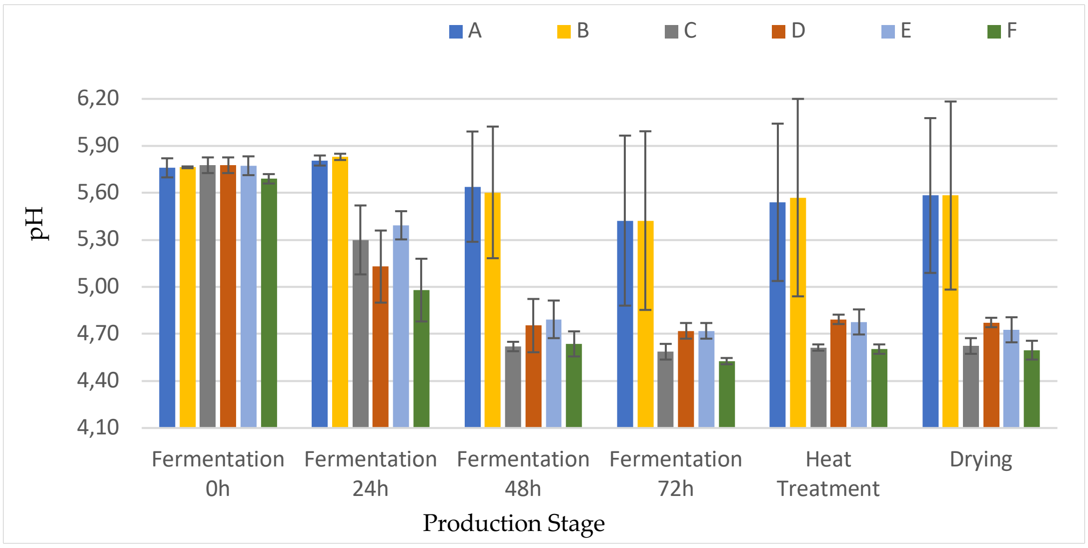

Figure 1. The changes in the pH value of HTS during the production (A: *S.aureus* and starter culture not inoculated, B: *S.aureus*, C: *S.aureus* / *L.plantarum*, D: *S.aureus* / *L.sakei*, E: *S.aureus* / *P.acidilactici*, F: *S.aureus* / *L.plantarum* / *L.sakei* / *P.acidilactici*).

The a_w values of HTS samples during the production are shown in Figure 2. The a_w value for all treatment at the beginning was found between 0.969 and 0.974. Fermentation time had a very significant effect on a_w value ($p < 0.01$). At the end of production (end product), a_w value was between 0.936 and 0.946. Among the hurdle effects such as nitrite, pH, redox potential and competing flora in fermented sausages, water activity plays an important role. Although *S. aureus* is a salt and nitrite resistant foodborne pathogen microorganism, it is very acid sensitive. pH along with a_w may play a more active role in inhibition of this pathogen (Kaya and Kaban 2019).

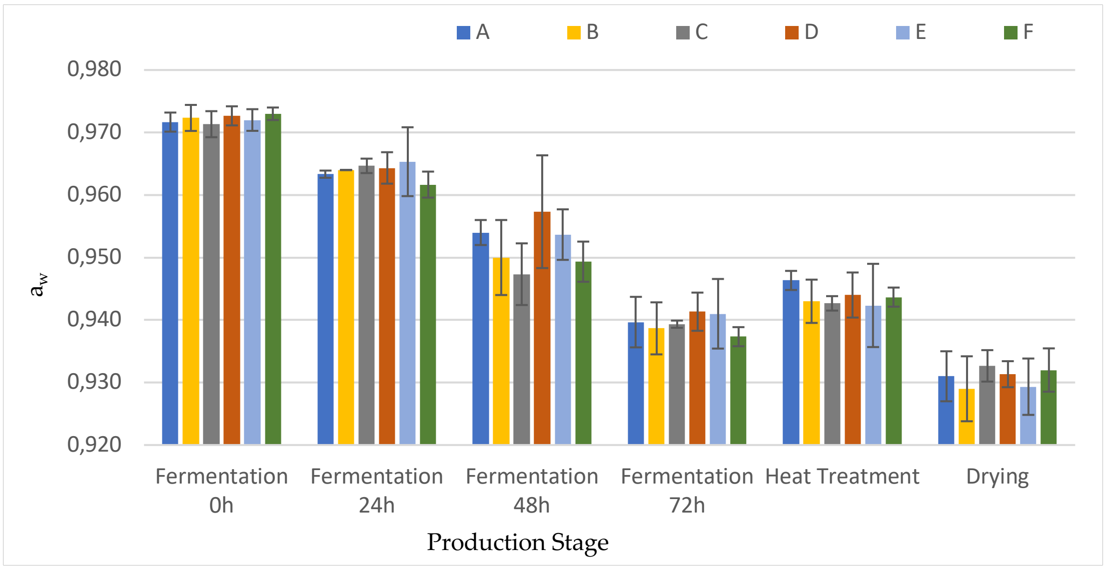

Figure 2. The changes in the a_w value of HTS during the production (A: *S.aureus* and starter culture not inoculated, B: *S.aureus*, C: *S.aureus* / *L.plantarum*, D: *S.aureus* / *L.sakei*, E: *S.aureus* / *P.acidilactici*, F: *S.aureus* / *L.plantarum* / *L.sakei* / *P.acidilactici*).

3.2. Staphylococcus aureus

The changes in the *S. aureus* of HTS during the production are shown in Figure 3. In the group A, the number of *S. aureus* was found below the limit of quantification (<2 log CFU/g) during production. In group B (*S. aureus* inoculated), *S. aureus* showed little growth (0.48 log unit) after 24 h of fermentation. An increase in the number of *S. aureus* (0.82 log unit) was also observed after 48 h of fermentation. After 72 h, an increase in the number was not determined. Since *S. aureus* is an acid sensitive microorganism, the rate and degree of acidification during fermentation play an important role in inhibition of this microorganism (Kaban and Kaya 2006; Lücke 1998; Wang et al. 2018; Yılmaz Topcam et al. 2024). In the first 24 h of fermentation, no decrease in mean pH (5.83) was observed in group B, and even a higher pH compared to the initial pH was observed. The pH increase in this group, which did not include autochthonous strains, is thought to be related to the proteolytic activities of microorganisms in the meat environment. After 48 h of fermentation, there was a slight drop in mean pH (5.6). Despite this, the number of *S. aureus* continued to increase. At the end of 72 h, the average pH value was determined to be 5.42 and no significant increase in the number was observed. Similar results were observed in previous studies on sucuk (a type of dry fermented sausage) (Erol and Hildebrant 1992; Kaban and Kaya 2006). In contrast, as can be seen in Figure 3, in the HTS group (C, D and E) inoculated with *S. aureus*, the autochthonous strains inhibited the growth of this food-borne pathogen. These results indicated that the autochthonous strains used starter cultures inhibited the *S.aureus* by lowering the pH value during fermentation. These findings indicated observed that the acid formation during fermentation has a very important hurdle effect in HTS. In studies about Pepperoni and Geno sausage (Raccahch 1981), sucuk (Yılmaz Topcam et al. 2024) and other fermented sausage varieties (Gonzalez-Fandos et al. 1996, 1999; Marcy et al. 1985; Sameshima et al. 1998; Campaniello et al. 2020; Tangwatcharin et al. 2020), LAB has been reported to play an important role in the inhibition of *S. aureus*.

In the present study, the temperature in heat treatment stage was gradually increased, and the cooling stage was started when the internal temperature was 68 °C. With the heat treatment application (core temperature 68 °C), the number of *S. aureus* decreased below the detectable limit in all groups. *S. aureus* is a heat treatment sensitive microorganism. The D value of this microorganism is approximately 1 min at 65 °C (Lücke 1998).

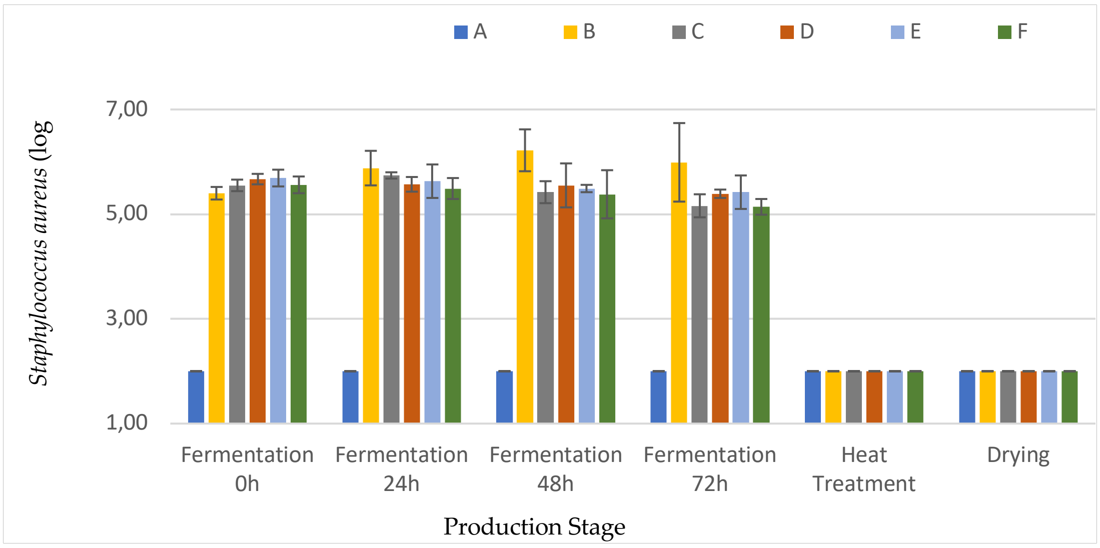

Figure 3. The changes in the *S. aureus* of HTS during the production (A: *S.aureus* and starter culture not inoculated, B: *S.aureus*, C: *S.aureus* / *L.plantarum*, D: *S.aureus* / *L.sakei*, E: *S.aureus* / *P.acidilactici*, F: *S.aureus* / *L.plantarum* / *L.sakei* / *P.acidilactici*).

3.3. Lactic Acid Bacteria and Micrococcus/Staphylococcus

The use of autochthonous LAB showed a very significant impact on LAB of sausages ($p < 0.01$). Fermentation time showed also similarly effect on LAB ($p < 0.01$). The initial LAB numbers of A and B groups were found to be 2.56 ± 0.73 and 3.09 ± 0.46, respectively. The initial LAB numbers varied between 7.22 ± 0.15 and 7.96 ± 0.14 in the groups (C, D, E and F) with autochthonous strains. After 24 h of fermentation, LAB number increased to about 9 log CFU/g in samples contained autochthonous starter cultures, but remained at about 5 log CFU/g in A and B groups with no starter culture. The initial stage of fermentation is very important for the inhibition of *S. aureus*. As in group B, *S. aureus* could grow due to slow acidification by spontaneous LAB. According to these results, both autochthonous strains and mixtures of these strains cause good acidification during the fermentation stage and inhibit the growth of *S. aureus*. With the heat treatment applied after the fermentation stage, a significant reduction in LAB numbers was achieved (<2 log CFU/g) (Figure 4).

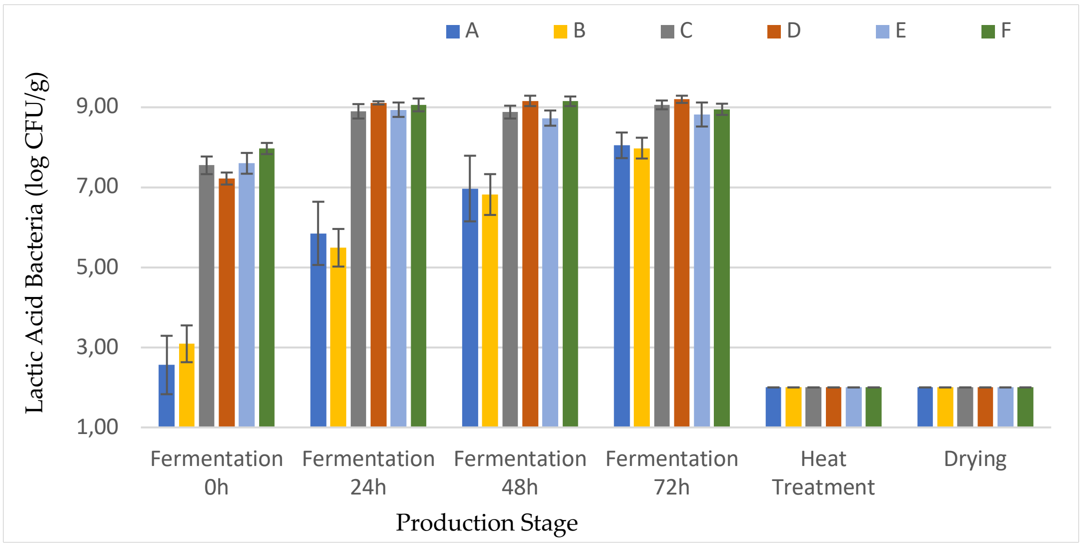

Figure 4. The changes in the LAB of HTS during the production (A: *S.aureus* and starter culture not inoculated, B: *S.aureus*, C: *S.aureus* / *L.plantarum*, D: *S.aureus* / *L.sakei*, E: *S.aureus* / *P.acidilactici*, F: *S.aureus* / *L.plantarum* / *L.sakei* / *P.acidilactici*).

In the present study, autochthonous strains had a very significant effect on *Micrococcus/Staphylococcus* number of HTS samples ($p < 0.01$). The changes in the *Micrococcus/Staphylococcus* of HTS during the production are shown in Figure 5. In the group A, the number of *Micrococcus/Staphylococcus* increased significantly due to the slowly decrease in pH. The initial number, which was about 4 log CFU/g, increased by about 2 log units after 72 hours of fermentation. Similarly, the number of *Micrococcus/Staphylococcus* increased as the fermentation time progressed in the B group contaminated only with *S. aureus*. In the presence of autochthonous LAB the number of *Micrococcus/Staphylococcus* did not show any significant change during fermentation. Morever, after heat treatment, the significant reductions were observed in all groups (<2 log CFU/g). No significant change was observed during the drying stage (Figure 5).

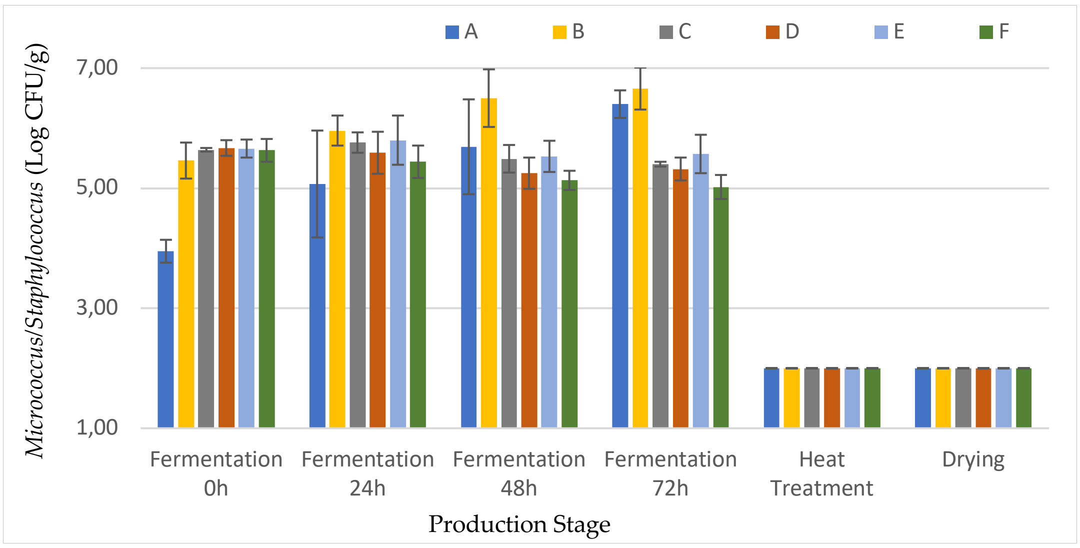

Figure 5. The changes in the *Micrococcus/Staphylococcus* of HTS during the production (A: *S.aureus* and starter culture not inoculated, B: *S.aureus*, C: *S.aureus* / *L.plantarum*, D: *S.aureus* / *L.sakei*, E: *S.aureus* / *P.acidilactici*, F: *S.aureus* / *L.plantarum* / *L.sakei* / *P.acidilactici*).

3.4. Enterotoxin Formation

In order to determine the enterotoxin production ability of *S. aureus* under production conditions of HTS, sausage groups contaminated with *S. aureus* were subjected to enterotoxin analysis using the VIDAS method. In the group B, *S. aureus* reached around 10^6 CFU/g during fermentation stage. However, no enterotoxin was detected in the final product. In another HTS groups with starter culture (C, D, E and F groups), no enterotoxin was also detected. In previously studies, it has also been reported that enterotoxin may not always be formed at high numbers of *S. aureus* (Bang et al. 2008; Notermans and van Otterdijk 1985). This study indicated also that enterotoxins may not be formed under fermentation conditions of HTS, even at the high *S. aureus* number. However, it is believed that the use of lactic starter cultures was necessary to prevent or limit growth of *S. aureus* during fermentation stage of HTS.

4. Conclusions

According to the results, the decrease in pH during fermentation of HTS is very important hurdle effect for preventing the growth of *Staphylococcus aureus*. *Latilactobacillus sakei* S15 was more effective on the inhibition of *S. aureus* at early stage of fermentation, followed by *Lactiplantibacillus plantarum* S91. However, *S. aureus* number increased in the absence of autochthonous strains used starter cultures. On the other hand, no enterotoxin was detected in all groups under the processing conditions applied in the study. Besides all this, it is estimated that *S. aureus* can grow rapidly and reach high numbers at fermentation temperatures above 22 °C. Therefore, a rapid pH drop during fermentation is of great importance for the control of *S. aureus* at both low and high fermentation temperatures. For this reason, autochthonous lactic starter cultures should be used in the production of HTS.

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Conflicts of Interest: The authors declare that they have no conflict of interest.

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The Effects of High Pressure Processing on Total Mesophilic Aerobic Bacteria Number and Color Properties of Frozen and Unfrozen Minced Beef

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HIGHLIGHTS

- The increase in freezing process, pressure level and application time increased inactivation.
- Pressure level was the most effective factor in total mesophilic aerobic bacteria inactivation.
- The most effective inactivation at 300 MPa HPP in frozen and unfrozen samples occurred at -5 ˚C for 15 min.
- When freezing and pressure were applied together, the minced beef color was obtained closer to fresh characteristics.

Abstract

High hydrostatic pressure processing (HPP) is a cold pasteurization technology that can be applied after packaging to products damaged by heat treatment. In this study, the effects of different levels (300, 350 and 450 MPa) of pressure applied at different temperatures (-5, 0 and 10 ˚C) and durations (5, 10 and 15 min) on the total mesophilic aerobic bacteria count (TMAB) and color values of frozen and unfrozen minced beef were investigated. The most effective factor on the number of TMAB was pressure. Freezing resulted in increased inactivation. In the application performed at constant temperature (10 ˚C), the difference in inactivation between frozen and unfrozen samples was seen maximum at 300MPa pressure application. Inactivation increased with increasing pressure level and time. At different application temperatures, the most effective inactivation of 300 MPa HPP in frozen and unfrozen samples occurred at -5 ˚C in 15 minutes. The increase in *L** value of frozen samples was less than that of non-frozen samples. This contributes to the preservation of freshness properties in meat. An increase in the *L** value was observed with the increase in pressurization time. Increasing the pressure level caused a decrease in the a* value, and freezing caused an increase in the *a** value. It was determined that the 300-450 MPa HPP range was not large enough to observe changes in *b** values. ΔE values in frozen samples were determined to be higher than in non-frozen samples. If freezing and pressure are applied in combination, a microbiologically safer product with a color closer to fresh properties can be obtained.

Keywords: Beef mince; Color of meat; High pressure treatment; Microorganisms in meat

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1. Introduction

The meat industry is trying to meet increasing consumer demands for high-quality raw meat with a long shelf life (Businesswire 2019; Rajendran et al. 2022). High hydrostatic pressure processing (HPP) is a non-thermal post-packaging technology that allows to extend shelf life, maintain high sensory and nutritional qualities and improve food safety in these products where other technologies such as heat treatment are not suitable (Grossi et al. 2014; Cava et al. 2021). It can reduce the presence of foodborne pathogens and spoilage microorganisms through HPP (Hayman et al. 2004; Patterson 2005; Simonin et al. 2012; Torres and Velasquez 2008). Therefore, it can be considered as an alternative to the use of chemical preservatives (Lerasle et al. 2014). The first effect of high pressure on microorganisms is the disruption of the membrane (Demir and Evrendilek, 2024). Inactivation depends on HHP conditions (pressure, time), properties of foods (pH, fat content, water activity, spices, etc.) (Bover-Cid et al. 2011). It also depends on different factors such as Gram type, strain and growth stage of the microorganisms (Garriga et al 2004; Rivas-Cañedo et al. 2009; Smelt 1998; Argyri et al. 2018).

In general, Gram-negative bacteria are more sensitive to pressure than Gram-positive bacteria, but there are large differences in pressure resistance among various strains of the same species (Cheftel and Colioli 1997). The application of high pressure in the range of 300–600 MPa has proven effective in inactivating vegetative cells. Unless HPP is performed at temperatures around 100 ˚C, more than 1000 MPa is needed to inactivate bacterial spores (Masana et al. 2015). Cells in stationary phase are more resistant to pressure. The growth phase of microorganisms may affect the HPP (Pagán and Mackey 2000; Mañas and Mackey 2004). The resistance of microorganisms to pressure increases with decreasing water activity (Cheftel and Colioli 1997; Jung et al. 2003). Although HPP is a non-thermal process, adiabatic heating provides a 2.5–4.8 ˚C/100 MPa increase in product temperature, depending on water and oil content (Patazca et al. 2007; Boziaris et al. 2021). In muscle food products, the increase in temperature combined with pressurization typically destabilizes the proteins. This results in enhanced drip loss and undesirable changes in color or other sensory properties (Gudbjornsdottir et al. 2010).

Ranges of HPP application (300–600 MPa) in pasteurization of fresh red meats can cause undesirable discoloration (Carlez et al. 1995; Realini et al. 2011). This defect can be reduced by combining of HPP with other processes, such as curing or freezing (Szerman et al. 2011; Vaudagna et al. 2012; Bulut 2014a). In their study Fernandez et al. (2007) evaluated the high pressure-low temperature process combined with freezing, and they concluded that freezing protects the meat from the harmful effect of pressure on color by regaining its original color after thawing. Although the initial investment is still high, pressure processes consume less energy than heat treatment. This is a factor that contributes to its commercial competitiveness (Garriga et al. 2004).

In this study, the effects of different degrees of pressure applied at different temperatures and times on the total microorganism number and color values of frozen and unfrozen minced beef were examined.

2. Materials and Methods

2.1. Material

In this study, beef tenderloin, which had the least amount of collagen, a homogeneously distributed fat tissue and water content, was preferred. *Longissmus costarum* muscle obtained from the dorsal region of Holstein cattle carcasses aged around 2 years was used (average 4% fat). After slaughtering, the carcasses are rested for 48 hours in cold storage at (1.0-4.0 ˚C). Then, they were brought to the laboratory in cold conditions in polyethylene bags in 1-2 kg masses. Fresh, lean, boneless meat samples were minced by passing them twice through a refrigerated meat grinder equipped with a 3 mm perforated plate, then kept at 4.0±2 ˚C until the experiment.

2.2. Method

2.2.1. Preparation of minced beef samples for pressurization process

Minced beef samples were homogenized using a food processor (Bosch, Germany). Then, the minced beef samples were packaged in air- and water-tight Polyamide/Polyethylene bags (Ege Plastik, İzmir), (90 µ thick, 83.7 g/m² weight, 10.4 cc/100 in²/day oxygen permeability and 0.55 g/100 in² /day moisture permeable) using a vacuum packaging machine (MV-20, Lipovak, Gebze, Turkey). Double packaging was done with bags of 10*2.5 cm size. During packaging, the samples remained at room temperature for about 4 hours. Before HPP, half of the samples were frozen in a deep freezer (model: RT54QMSW, Samsung, Korea) at -21.0±5 ˚C in superfreezing mode for overnight (approximately 12–18 h). The other half of the samples were left in the refrigerator compartment of the device at +4.0±2 ˚C overnight (approximately 12-18 hours) and then the HPP process was applied. The frozen samples were not thawed before applying the HPP process. All samples were prepared in triplicate for each experiment. For convenience in the study, short names are given to the examples. F+ refers to frozen samples, F- refers to unfrozen samples.

2.2.2. Estimated temperature change in meat samples before HPP

Since the temperatures of the samples needed to be known before applying pressure, a thermocouple of the thermometer (Huato HE800, China) was placed from the upper end of the bag containing the sample to the center of the sample, and then frozen in the freezer with the thermocouple connected to the sample. After freezing for approximately 12-18 hours, the sample was removed from the freezer and placed in the pressure chamber. The non-frozen group was kept in the refrigerator for approximately 12-18 hours and was removed from the refrigerator and placed directly in the pressure chamber. Then the pressurization process was started. The pressurization temperature was adjusted according to the test temperature before pressurization using a cooler integrated into the system (model RE1050S, Lauda Dr R. Wobser GmbH & Co. KG. Germany). Temperature change was recorded every 30 seconds for up to 3 minutes.

2.2.3. High-pressure treatment and operating parameters

A high-pressure system used to process the samples had a 0.7-L working volume (model MSE-CIP-WB-5500, MSE Technology Ltd., Gebze, Turkey). Details of the system are given by Şayin Sert and Coşkun (2022). Pressure applications were carried out at 300, 350 and 450 MPa, in the temperature range of -5 ˚C and 10 ˚C, for 5, 10, 15 min. Ideally, the maximum working pressure was chosen as 450 MPa in this study, as it was aimed to reduce investment costs and minimize the change in the color and textural properties of the meat. All pressurization experiments were repeated three times for each parameter.

2.2.4. Microbiological analysis

Samples (10 g) were mixed with 90 ml PBS pH 7.1 and homogenized using a stomacher (model Seward 400, UK) at 200 rpm for 1 min. Serial dilutions were prepared using PBS pH 7.1. Plate Count Agar (PCA) (Merck, Germany) was used as the medium for total mesophilic aerobic bacteria (TMAB) enumeration. Incubation was carried out at 37 ˚C for 24-48 hours (Bulut 2014b). Microbial reduction was expressed as logarithmic reduction, corresponding to the logarithmic difference between the initial number of microorganisms before the pressure treatment and the number of surviving microorganisms after the pressure treatment.

2.2.5. Color analysis

Color measurements in ground meat were made using a Konica Minolta model CM-5 colorimeter (MinolTMABo, Ltd, Osaka, Japan). Three parallel samples were prepared for each experiment. After all samples were kept at approximately 25 ˚C for 20 minutes, they were placed in a petri dish and allowed to come into contact with oxygen by mixing with a spatula for approximately 1 minute until a homogeneous mixture was obtained. Then, the samples were placed in the petri dish of the device for color measurements at room temperature (25 ˚C) and measurements were made. CIE L^* (brightness), a^* (redness) and b^*

(yellowness) values were measured three times on each sample and the average of the three readings was recorded. Total color difference (ΔE) was calculated using the following equation (Jung et al. 2003). Research was carried out in comparison with untreated control samples, and color values of unpressurized samples were used to calculate ΔE (Bulut 2014a)

$$\Delta E = [(L^*-L_0)2 + (a^*-a_0)2 + (b^*-b_0)2]1/2$$

2.2.6. Statistical analyses

Statistical analysis of the data was carried out using SPSS v.16.0. (SPSS Inc., Chicago). Statistical analysis of the study was carried out in a random plots 3x3x3 factorial experimental design. Significant sources of variation were compared using Duncan's multiple comparison test. The significance of the variables is interpreted as a significant change on the dependent variables if P is less than 0.05.

3. Results and Discussion

*3.1. Total mesophilic aerobic bacteria numb*er

The total microorganism load in meat determines shelf life and spoilage due to metabolic activity. The presence of microbes, increases the risk of spoilage due to greening, off-flavor formation, gas production, or textural defects (Fougy et al. 2016; Vasilopoulos et al. 2015; Rajendran et al. 2022). Therefore, it is important to study the effect of combination technologies on the total number of viable bacteria in meat.

Table 1 shows the effect of pressure level and pressurization time on the TMAB number. According to the statistical analysis results, freezing situation, pressure, time, freezing situation*pressure and pressure*time factors were found to be significant (P<0.05). The most effective factor in TMAB inactivation was found the pressure factor (p<0.05). While there was a 2.24 log cfu/g decrease at 300 MPa according to all time averages, it was observed that there was a 3.35 and 3.97 log cfu/g decrease at 350 and 450 MPa, respectively. The biggest difference between the TMAB number of frozen and unfrozen ground meat before HPP was detected after 15 minutes of pressure application at 300 MPa. The smallest difference was obtained in 450 MPa applications. The reason for the high inactivation in frozen samples may be that ice crystals, which increase in size during frozen storage, mechanically damage the tissues (Koch et al. 1996).

In the study of Carlez et al. (1994), 200, 300, 400 and 450 MPa pressure was applied to ground meat for 20 minutes at 20 ˚C. While total bacteria were slightly affected at 200 MPa, a 0.5-3 log decrease was observed at 300 MPa, a 3 log decrease at 400 MPa, and a 3-5 log decrease at 450 MPa. This confirms that higher pressure level leads to a greater reduction in bacteria in meat (Shigehisa et al. 1991). The effect of high pressure on microorganisms depends on the type of microorganisms present and the composition of the food (Hoover et al. 1989). In Kim et al.'s (2018) study, marinated beef samples were subjected to HPP treatment at 550 MPa for 5 minutes at 10 ˚C. After treatment, the TMAB number of the treated samples (3.99 to 5.19 log cfu/g) was lower than those of the control samples (4.91–6.28 log cfu/g). In another study, while the TMAB number in fresh beef before pressurization was 3.53 ± 0.23 log cfu/g, at 650MPa 10 min pressurization, there was a significant decrease in both unfrozen (20 °C) and frozen (-35 ˚C) samples (>2 log cfu/g) occurred. After pressurization, the counts were below the limit of detection (<2 log cfu/g) (Fernandez et al. 2007). Fernandez et al. (2007) emphasized that further research is needed to clarify whether combined treatments (conventional freezing process + HPP, low temperature) have an effect such as complete microbial inactivation or cell damage and to evaluate microbial growth during refrigerated storage. In Bulut's (2014a) study, as a result of applying pressure to minced beef at 300 MPa for 5 minutes at 10 and 20 ˚C, the average TAC reductions observed in frozen samples were log cycles of 2.4 and 2.2, respectively. These figures are approximately four times higher than the log reductions obtained in unfrozen samples after pressure treatment at the same temperatures of 10 and 20 ˚C, which are log cycles of 0.5 and 0.6, respectively.

Table 1. The effect of HPP (300, 350, 450 MPa, 5 min, 10 min, 15 min, 10 ˚C) applied to fresh minced beef on the logarithmic decrease in the number of TMAB

		N_0TMAB (log cfu/g)		Logarithmic Decrease (log cfu/g)	
Pressure (MPa)	**Time (min)**	**F-**	**F+**	**F-**	**F+**
300	5	6.36±0.36	5.85±0.48	1.51±0.25^{aA}	2.24±0.89^{aA}
	10	6.36±0.36	5.85±0.48	1.64±0.11^{aB}	2.15±0.52^{aB}
	15	6.36±0.36	5.85±0.48	2.03±0.17^{aC}	3.85±0.52^{aC}
350	5	4.81±0.11	4.37±0.15	2.41±0.82^{bA}	2.94±0.49^{bA}
	10	5.81±1.10	5.93±0.69	3.76±1.09^{bB}	3.79±0.67^{bB}
	15	6.50±0.91	6.22±2.30	3.44±1.07^{bC}	3.54±0.99^{bC}
450	5	4.85±0.35	4.68±0.35	2.93±0.25^{cA}	2.87±0.54^{cA}
	10	5.26±0.82	6.08±0.51	4.25±0.60^{cB}	4.33±0.65^{cB}
	15	6.15±0.42	5.81±1.10	4.70±1.31^{cC}	4.75±1.17^{cC}

N= 6, Results are given as mean ± standard deviation. F-:Unfrozen, F+:Frozen
Lowercase letters indicate the difference between pressures.
Capital letters indicate the difference between periods

Microorganisms are more affected by high pressure applications outside optimum growth temperatures (Moussa et al. 2007; Ritz et al. 2000; Yuste et al. 1999). Because microbial cell membranes can deteriorate more easily at temperatures beyond optimum growth temperatures (Smelt 1998; Bulut 2014a). Microbial cell membranes, which are normally semi-crystalline gels, can become stiffer and sensitive to high pressure at lower temperatures (ter Steeg et al. 1999; Bulut, 2014a).

Table 2 shows the effect of pressurization temperature (-5, 0, 10 ˚C) and pressurization time (5, 10, 15 min) at constant pressure level. According to the results, the interaction factors freezing situation, temperature, time, freezing situation*temperature, temperature*time, freezing situation*temperature*time are significant in these study parameters (P<0.05). It was observed that all factors had high impact values in inactivation. Maximum TMAB inactivation at 300 MPa (5 min) was observed at -5 ˚C (2.96 log cfu/g) in F+ samples (Table 2). At the same pressure level, inactivation increased as the temperature decreased and the time increased. There was a greater microbial reduction in F+ samples compared to F- samples in TMAB with 300 MPa HPP at all temperatures. Freezing increased inactivation at all times and temperatures. The highest death level occurred at -5 ˚C, considering all period averages. While the time change was not effective at 0 ˚C, the decrease in 15 min at -5 ˚C and 10 ˚C increased significantly (P<0.05). According to the average of all temperatures in the F- group, the mortality level at 5, 10 and 15 minutes was 1.82, 1.81, 2.61 log cfu/g, respectively, while in the F+ group, it was 2.24, 2.41, 3.69 log cfu/g, respectively. It is thought that the temperature should be lowered below 0 ˚C to achieve higher inactivation at low temperatures.

Table 2. Effect of HPP (300 MPa; -5, 0, 10 ˚C; 5, 10, 15 min) applied to fresh minced beef on the logarithmic decrease in the number of TMAB

			N_0 TMAB (log cfu/g)		Logarithmic Decrease (log cfu/g)	
Pressure (Mpa)	**Temperature (˚C)**	**Time (min)**	**F-**	**F+**	**F-**	**F+**
300	10	5	6.36±0.36	5.85±0.48	1.51±0.25^{bA}	2.24±0.89^{bA}
		10	6.36±0.36	5.85±0.48	1.64±0.11^{bA}	2.15±0.52^{bA}
		15	6.36±0.36	5.85±0.48	2.03±0.17^{bB}	3.85±0.52^{bB}
	0	5	6.30±0.56	5.83±0.48	1.58±0.49^{aA}	2.18±0.22^{aA}
		10	6.65±0.71	4.55±0.58	1.48±0.55^{aA}	2.07±1.32^{aA}
		15	6.86±0.42	4.60±0.65	1.97±0.13^{aB}	2.23±0.13^{aB}
	-5	5	6.30±0.58	5.70±0.71	2.37±0.30^{cA}	2.96±0.27^{cA}
		10	6.65±0.71	6.09±0.12	2.33±0.02^{cA}	3.04±0.02^{cA}
		15	6.65±0.71	6.09±0.12	3.84±0.06^{cB}	5.00±0.15^{cB}

N= 6 Results are presented as mean ± standard deviation. F-:Unfrozen, F+:Frozen
Lowercase letters indicate difference between temperatures
Capital letters indicate the difference between periods.

In one study, Malinowska et al. (2013) stated that the initial TMAB number in uninoculated pork and beef was 4.3 log cfu/g. They reported that this number was not changed by the 60 MPa level of HPP applied at -5 ˚C, and that 1.1 and 0.6 log cfu/g reduction was achieved in pork and beef, respectively, with the 193 MPa level of HPP (-20 ˚C). At room temperature, the TMAB level of beef was insignificantly affected by pressure treatments of 200 MPa or less. Fernandez et al. (2007) reported reductions in ATC (>2 log 10 cycles) with a count below detection limits after HHP treatment (at 650 MPa and −35 ˚C for 10 min) in frozen beef samples. Additionally, Carlez et al. (1994) reported that they achieved a 3 and 5 log cfu/g reduction in total flora with the application of 400 and 450 MPa high pressure, respectively. In our study, a 5 log cfu/g reduction was achieved in F+ samples with 300 MPa (-5 ˚C, 15 min) HPP. The study results are in agreement with the results of other researchers. Different results at similar pressure parameters may vary due to different initial microbial load levels and different microflora in fresh meat. Initial TMAB numbers in ground meat samples were in the range of approximately 4.85-6.86 log cfu/g. Under normal circumstances, a meat sample with these numbers is considered low quality in terms of microbial quality. Considering that the average TMAB numbers in beef are 4-4.5 log cfu/g, according to the results of this study, it is understood that the microbial load can be significantly reduced by the application of 300 MPa (-5 ˚C, 15 min) and 450 MPa (10 and 15 min) HPP. However, in these parameters, the color and texture changes of the meat and the parameters that can eliminate pathogenic microorganisms should be analyzed.

3.2. *Effect of HPP on color parameters of fresh minced beef*

The findings obtained as a result of 350/450 MPa (time effect at 300 MPa at 10 ˚C was not studied), 10 ˚C, 5, 10, 15 min HPP are shown in Figure 1. While the pressure factor was found to be effective on all dependent variables (*L**, *a**, *b**,ΔE) in minced beef samples, freezing situation affected *L** and *a** variables the most (P<0.05).

While the *L** values of unfrozen samples at 350 MPa 10 ˚C 5 min increased by 8.11 units compared to the control samples, the *L** value of frozen samples increased by 6.55 units. While the *L** values of the samples that were not frozen at 450 MPa 10 ˚C, 5 min increased by 13.35 units compared to the control samples, this value was 7.96 in the frozen ones. While the average *L** value difference between two pressure values increased in

F- samples, this difference disappeared in F+ samples. With increasing time, an increase in the *L** value was observed in general.

*L**

Researchers attributed the color lightening in meat as a result of HPP to the coagulation of myofibrillar and sarcoplasmic proteins, globulin denaturation, and the displacement or release of the heme group (Carlez et al. 1994). However and Xiong (2000) reported that color and texture deterioration in meat is related to protein oxidation. Although color criteria in fresh meat depend on HPP parameters, in HPP applications above 0 ˚C, there may be a decrease in redness (*a**) or an increase in lightening (*L**) in the color of meat (Vaudagna et al. 2012; Marcos et al. 2010).

The study results regarding color lightening during HPP were found to be similar to the results of this study. As the pressure increased in unfrozen meat, the color lightening increased. Similar to our study, in the study conducted by Vaudagna et al. (2012), no significant change was observed in the *L** value of cured beef carpaccio in samples frozen at -30 ˚C as a result of application at 400 MPa for 1 to 5 minutes. An 8.57 br increase in *L** value was detected in unfrozen (20 ˚C) samples. Montero and Gomez (2005) reported that the increase in *L** value and decrease in *a** value depend on the critical pressure threshold value rather than time. In this study, freezing the samples contributed to the preservation of freshness properties on the *L** value of meat against the effects of pressure changes.

In this study, a significant color difference occurred in the meat color of F- samples at 450 MPa (10 ˚C, 10-15 min) pressure. It has been reported that HPP at low temperature is effective in reducing color change in meat (Fernandez 2007; Marcos et al. 2010; Vaudagna et al. 2012; Bulut 2014a). The effect of pressure on beef frozen at subzero temperature is likely to be milder and reversible. In this case, myoglobin may return to its natural conformation with thawing and, accordingly, normal color can be regained in fresh meat (De Alba et al. 2012).

*a**

Compared to pressure time, pressure level and freezing situation were more effective parameters for *a** value (redness). Similarly, Bulut (2014a) reported that in his study on minced beef at low temperatures of 300 MPa and subzero temperatures, only the freezing situation factor was effective regarding *a** values. Carlez et al. (1995) achieved a significant decrease in a* values between 300 and 500 MPa by pressurizing ground meat. Jung et al. (2003) found that pressures above 350 MPa (10 ˚C, 20-300 sec) caused decreases in the *a** value. They thought that in this change in *a** values, some changes occurred in the content of myoglobin pigments and especially in the form of metmyoglobin during application. Regarding this, Ma and Ledward (2013) stated that myoglobin is denatured above 400 MPa.

Jung et al. (2003) concluded that only the effect of pressure was significant in the change in ΔE (10 unit increase). In our study, *a** values of ground meat decreased with increasing pressure level. However, *a** values were found to be higher in frozen samples than in non-frozen samples. Mussa (1999) reported a decrease in redness in pork chops after 350 MPa (10–20 min, 25 ˚C) treatment. They reported that this decrease was due to the meat turning brown due to an increase in metmyoglobin (Fe^{3+}). Vaudagna et al. (2012), as in our study, when the level of the pressure applied to cured beef carpaccio for 5 minutes was increased from 400 MPa to 650 MPa, a decrease in the *a** value was detected in both frozen and unfrozen samples. Color changes after HPP in fresh meat can be limited by optimizing HPP process parameters (Bajovic et al. 2012).

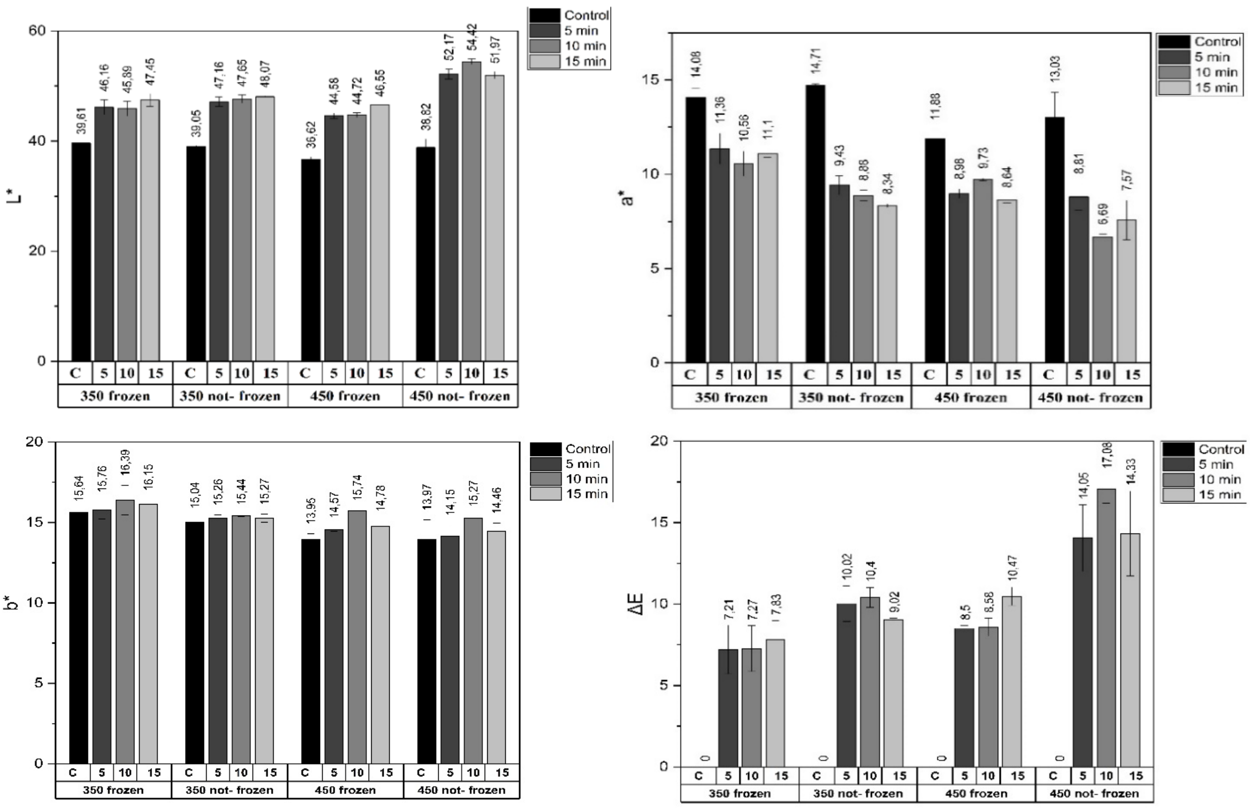

Figure 1. Changes in *L**, *a**, *b** and ΔE values in fresh minced beef after HPP (350 and 450 MPa, at 10 ˚C, for 5,10, 15 minutes)

*b**

There was a minimum increase in *b** values in both cases (F-, F+) when applying 350 MPa and 450 MPa pressure at 10 ˚C for 5 minutes. The increase continued as the pressurization time was increased to 10 minutes. A slight decrease in the *b** value was observed when the time was increased to 15 minutes at both pressure levels. Additionally, the effect of time and pressure level was not found to be significant for the *b** (yellowness) value of ground meat (P>0.05). It was thought that the 300-450 MPa HPP range was not large enough to observe changes in *b** values. However, in the study conducted by Vaudagna et al. (2012), when the pressure level was increased from 400 MPa to 650 MPa in cured beef carpaccio samples frozen at -30 ˚C for 5 minutes, an increase in the *b** value occurred, unlike in our study. In that study, a slight decrease in the *b** value was detected in unfrozen (20 ˚C) samples, as in our study. Since the curing was done in that study and the pressure intensities were different, it was thought that there may have been differences with the results in our study.

ΔE

ΔE values were determined to be higher in frozen samples than in non-frozen samples. In the case of combined application of freezing and pressure, the color of the ground meat was obtained closer to fresh characteristics. In addition, in this study, the color difference remained below the limit values in all frozen samples at 10 ˚C with 350 and 450 MPa HPP. Researchers reported a ΔE value of 10 units as significant color loss (Jung et al. 2003).

4. Conclusions

HP technology is an alternative to pasteurization that can be applied to extend the life of meat without the use of chemical additives. With this application, the properties of meat are preserved better than pasteurization. Various studies have been carried out to determine the most suitable parameters for the application of this technology. Although there are many studies on different pressure levels, time and temperature applications, there needs to be more studies on freezing the meat before application. The results of this study showed that freezing of minced beef before HPP was very effective in reducing the total mesophilic aerobic bacteria count. The color values of frozen minced beef were preserved better than non-frozen minced beef.

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Analysis of Characters Affecting Yield and Yield in Chickpea

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HIGHLIGHTS

- Chickpea is an important legume plant in terms of its protein content.
- Chickpea plants need to be improved in terms of yield and characteristics affecting yield.

Abstract

It aimed to reveal some chickpea varieties' yield and yield parameters with descriptive statistics in Yozgat ecological conditions for two years in 2022 and 2023. In the study, 10 chickpea varieties (Azkan, Çağatay, Çakır, Gökçe, Hasanbey, İnci, Seçkin, Sezenbey, Uzunlu 99 and Zuhal) were used as materials. In the study, plant height (cm), first pod height (cm), biological yield (g), number of pods per plant (pcs), number of seeds per plant (pcs), seed yield per plant (g), hundred seed weight (g), harvest index. (%) and seed yield per decare (kg da^{-1}) characteristics were examined. As a result of the study, it was revealed that chickpea varieties were significantly affected by all the examined agronomic characteristics except the height of the first pod. According to the two-year averages of chickpea varieties, the number of pods per plant varied between 13.67-39.33 units, the number of seeds per plant varied between 12.00-28.67 units, seed yield per plant varied between 4.26-8.37 g, hundred seed weight varied between 28.67-36.37 g and seed yield per decare varied between 82.71-124.5 kg da^{-1}. It was observed that Gökçe, Çakır, and Çağatay chickpea varieties included in the study had high seed yield.

Keywords: Yozgat; Chickpea; Variety; Yield parameters; Descriptive statistics

1. Introduction

The chickpea plant is significant among pulses grown for food and is very important for Turkey. Besides its importance in human nutrition, pulses also have many benefits, including being a source of plant-based protein crucial for animal nutrition. Mainly because it requires less water compared to other pulses, the chickpea plant is suitable for arid conditions, with its cultivation dating back 7,000 years in the Middle East and 5,000 years in Anatolia (Pellet 1988). The chickpea plant is especially preferred due to its essential amino acids, vitamins, and protein content.

According to 2022 data, chickpea cultivation is carried out on 14.8 million hectares worldwide, with approximately 10 million hectares in India. In Turkey, chickpeas are grown in an area of 456,000 hectares, but

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chickpea cultivation in our country has shown a decreasing trend of about 10% in recent years (Burcu 2021). While the world average yield is reported as 122.18 kg da^{-1}, Turkey's yield is above this average at 127.06 kg da^{-1}, with China holding the top position among countries with a yield of 523 kg da^{-1} (FAO 2022).

As the world population increases uncontrollably, migrations also force countries to change their plans. Consequently, due to future concerns, governments are trying to develop behavioural patterns beyond expectations. Food supply is the most significant concern (Dowd and Burke 2013; Ustaahmetoğlu and Toklu 2015). Joachim (2009) stated that countries are starting to face risks in terms of food supply, and those who are not self-sufficient may face much more significant problems in the near future. Thomas (2006) emphasized that controlling food security and trade will become necessary and that serious measures must be taken. Kıymaz and Şahinöz (2011) pointed out that ensuring food security requires the sufficient cultivation of the right products, highlighting the importance of strategic products.

The importance of chickpeas as a strategic product for our country continues to increase daily. The high cost of animal-based proteins drives consumers towards plant-based proteins (Topalak and Ceyhan 2015; Sözen et al. 2021). In addition to increasing productivity, conducting studies that protect the soil and enhance sustainability is necessary. While pulses for food possess these characteristics, chickpeas seem highly suitable for our country's ecology. Therefore, chickpea plants need improved yield and yield-affecting traits (Ceyhan et al. 2012a,b; 2013; Kahraman et al. 2016; Sözen and Karadavut 2019).

In this study, we aim to evaluate the cultivation of registered chickpea varieties under arid conditions in our country and determine whether these varieties are ready for the future. For this, it is necessary to see their performance in arid and semi-arid conditions. Care was taken to select the selected varieties and regions in accordance with the purpose of the study. Accordingly, developing appropriate models will help us in this effort (Karadavut et al. 2019). Growing plants under natural conditions in different locations and years will provide reliable information about their performance. The information obtained will help us in the selection of the best plants that can reduce the effects of drought.

2. Materials and Methods

The field trials of the research were established during the chickpea growing seasons of 2022 and 2023 on the agricultural land of a farmer named İbrahim Hakkı in Toprakpınar village, Sarıkaya district, Yozgat province.

2.1. Materials

The materials of the research consist of 10 chickpea varieties (Azkan, Çağatay, Çakır, Gökçe, Hasanbey, İnci, Seçkin, Sezenbey, Uzunlu-99, and Zuhal) that were registered by research institutes affiliated with TAGEM in different years. The selected varieties are genotypes that have been tried to be grown under dry conditions in different regions of Turkey for many years. However, they have not been grown in the areas where the experiment was conducted except for Azkan and Gökçe. Their areas are also very limited and irrigated areas.

2.2. Soil Characteristics of the Trial Site

The land where the research was conducted for two years is a first-class land with a nearly flat topography showing loamy characteristics. When evaluating the soil properties of the experimental field where the studies were conducted, it was determined that the soil is very slightly alkaline, has good organic matter, is sufficient in available phosphorus and potassium, is non-saline in salt content, and has shallow lime content.

In the study where the research was carried out for two years, soil analyses were carried out in the Ahi Evran University Central Laboratory. The trial area is a first-class land with almost flat topography, showing loamy characteristics. When the soil characteristics of the trial area where the studies were carried out were evaluated, it was determined that the soil was very slightly alkaline, had good organic matter, was sufficient in terms of available phosphorus and potassium, had no salt content and had shallow lime content. These evaluations were made according to Kaçar (1995).

2.3. Climate Characteristics of the Research Area

The climate values for the experimental years and long-term averages for the Sarıkaya district of Yozgat province, where the studies were conducted, are given in Table 1. When evaluating the table, it is seen that the average temperature in the experimental area during the growing seasons was the lowest in March (2.4 °C and 3.4 °C) and the highest in July (24.3 °C and 23.7 °C) for both years. These values are above the long-term average values. Regarding precipitation, March had the highest rainfall in the first and second years (83.3 mm and 71.5 mm), while the precipitation amounts in both years were below the long-term averages, except for March. As for humidity, no significant changes were observed in both years, with relative humidity values ranging between 48.6% and 77.1%. When Table 1 is examined, it is seen that while there is no significant change in humidity and temperatures compared to the average for many years, the precipitation in the region has decreased significantly in May and June. This is expected to be effective in the growth, development and differentiation of the varieties.

Tablo 1. Climate data for Sarıkaya/Yozgat

Months	Average Temperature (^{0} C)			Total Rainfall (mm)			Average Relative Humidity (%)		
	2022	2023	Long Years	2022	2023	Long Years	2022	2023	Long Years
March	2.4	3.4	3.4	83.3	71.5	68.2	77.1	72.8	70.9
April	6.7	7.1	8.5	20.4	35.9	57.8	73.9	69.3	64.9
May	15.8	15.2	13.4	41	52	59	54.3	59.6	62.9
June	20.2	19.5	16.9	33	28	63	57.8	58.3	59.3
July	24.3	23.7	20.2	18	10	23.1	48.6	51.3	52.8
Total				195.3	197.4	271.1			

2.4. Method

The research was conducted on the agricultural land of a farmer named İbrahim Hakkı in 2022 and 2023 and was established according to a randomized block design with three replications. In both years, the plot areas were arranged as 5 x 1.2 = 6 square meters, with each plot consisting of 4 rows. Throughout both years, sowing was performed at 30 cm row spacing, and 5-8 cm on the rows opened with a marker, and no space was left between the plots. Sowing was carried out on March 23 in the first year and on March 25 in the second year, and along with sowing, 15 kg of DAP fertilizer (2.7 kg N da^{-1} and 6.9 kg P_2O_5 da^{-1}) per decare was applied to the trial area, with hoeing done twice during the growing seasons. The harvest of the chickpea varieties in the trial areas during the research years was done manually between July 5 and July 25, when they reached harvest maturity. Plants in the 2.4 square meters area (4.0 m x 0.6 m) were harvested by excluding one row from each side of each plot and 50 cm from the beginning and end of the plot as border effects. In both years, plant height, first pod height, biological yield, number of pods per plant, number of seeds per plant, seed yield per plant, hundred seed weight, and harvest index were determined in 10 randomly selected plants from each plot, and the averages were calculated to determine the average values per plant.

Additionally, the seed yields per decare in kg da^{-1} were calculated from the plants harvested from each plot after removing the border effects. The results obtained over two years were primarily analyzed for descriptive statistics according to the examined characteristics, followed by variance analysis. The Duncan ($p<0.05$) multiple comparison test was applied to determine the differences among varieties. The effects of variety, year, and variety*year interactions were examined, and their significance was determined. Furthermore, the distribution of varieties by year was graphically analyzed to see the distribution of data for the varieties. The MINITAB 17 V statistical software package was used in the study.

3. Results

3.1. Plant Height

Descriptive statistics ve post hoc test results for the plant height of chickpea varieties are given in Table 2. When the table is examined, it is observed that the highest plant height was found in the İnci variety at 49.00 cm, followed by the Azkan variety at 48.17 cm. The çakır variety had the lowest value. According to variance analysis the differences between the years and the variety*year interactions were not found to be statistically significant. The lack of substantial changes across the years was attributed to the minimal climatic differences observed during the study period.

Table 2. Descriptive statistics of varieties for plant height

Varieties	Average	Gruplandırma
Azkan	48.17±1,17	AB
Uzunlu 99	45.17±2,41	AB
Gökçe	39.83±1,32	AB
Seçkin	47.33±1,29	AB
Hasanbey	41.33±1,13	AB
İnci	49.00±1,10	A
Çakır	37.67±1,67	B
Sezenbey	47.17±2.50	AB
Zuhal	42.50±2,47	AB
Çağatay	42.17±1,74	AB

When the average values of the varieties are examined, it is seen that the average height is 44.03 cm (Figure 1a). It was determined that the Azkan, Uzunlu, Seçkin, İnci, and Sezenbey varieties have values above the average plant height. In contrast, the Gökçe, Hasanbey, Çakır, Zuhal, and Çağatay varieties have values below the average. The İnci variety deviated the most above the average, while the Çakır variety deviated the most below the average. The distribution of plant heights by year for the varieties is shown in Figure 1b. When the figure is examined, it is seen that the distribution does not differ between years. Although the average curves appear different by year, their difference is insignificant.

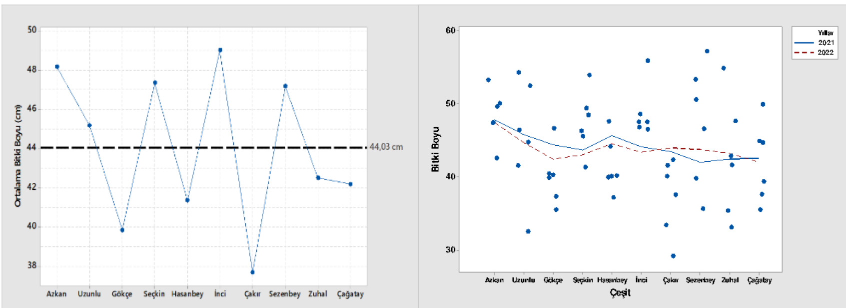

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Figure 1. Distribution of plant heights around the average and change in plant height over the years

The soil structure of the cultivated land is open to variability. The amounts of rainfall, humidity, and sunshine need to support this. However, this was different. In the study, among the differences between varieties, the İnci variety, with a height of 49.00 cm, was categorized in Group A, distinguishing it from the others. Conversely, the Çakır variety, with a height of 37.67 cm, was placed in Group B, while all other varieties fell into the AB category, indicating they were in the same group. There was no statistical significance among varieties within the same group. in her study on chickpea plants in Ayrancı / Karaman, found that plant height values vary between 41.0 and 52.0 cm in dry conditions. Ölmez et al. (2020) stated that the influence of environmental conditions on plant height was low in their density study conducted in Siirt. Similarly, Ali et al. (2008) found that the influence of environmental conditions on plant height variation was lower than for other traits in their study conducted in Pakistan. The first thing affected by drought conditions is generally plant height and it is expected that they will be short in general. The fact that plant height is similar to the results of other researchers suggests that the response of the varieties to drought is limited. This is considered promising considering that drought will increase slightly in the future.

3.2. First Pod Height

This trait is evaluated alongside plant height, and the first pod height should be as high as possible, mainly because it affects mechanical harvesting and the development of diseases. When examining the descriptive statistics for the first pod height, it is seen that the Azkan variety has the highest value at 32.67 cm (Table 3).

This is followed by the İnci variety at 29.83 cm. The lowest first pod height value was found in the Gökçe variety at 22.17 cm. Regarding standard deviation and variance, the Zuhal variety showed the highest values, with a standard deviation of 8.26 and a variance of 68.30, indicating that the Zuhal chickpea variety has broader limits for variability. The lowest standard deviation and variance were found in the Gökçe variety, with a standard deviation of 1.329 and a variance of 1.747. The highest coefficient of variation was also observed in the Zuhal variety, with a value of 31.19%. According to the results of the variance analysis, the variety*year interaction and the differences between varieties and years were not statistically significant. The insignificance of the differences in first pod height suggests that the varieties' responses in this regard are similar and that this difference will diminish over time. The insignificance of the interaction is particularly noteworthy.

Table 3. Importance of varieties, years, and interactions according to first pod height

Varieties	Average	Post Hoc
Azkan	32.67±2.44	A
Uzunlu99	27.67±2,47	A
Gökçe	22.17±0,42	A
Seçkin	29.33±2,21	A
Hasanbey	26.00±1,08	A
İnci	29.83±1,82	A
Çakır	24.167±0,73	A
Sezenbey	29.17±1,83	A
Zuhal	26.50±2,61	A
Çağatay	27.33±1,93	A

In terms of first pod height, the Azkan, İnci, Sezenbey, and Hasanbey varieties have values above the average. In contrast, the Seçkin, Uzunlu, Çağatay, Zuhal, Çakır, and Gökçe varieties have values below the average (Figure 2a). Notably, the Gökçe variety, having the lowest first pod height value, will seriously and negatively impact mechanical harvesting. When examining the first pod heights of the varieties by year, it is seen that the curves move similarly (Figure 2b). Notably, the Azkan variety has the highest first pod height in both years.

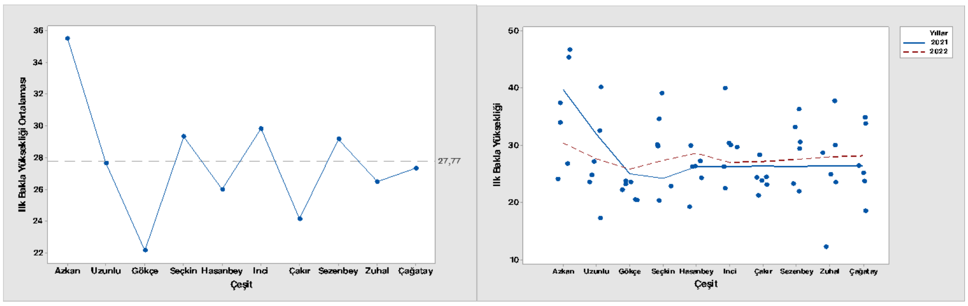

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Figure 2. Distribution of first pod heights around the average and change in first pod height over the years

Since the first pod height is influenced by plant height, the insignificant interaction, similar to plant height, is considered an expected result. Pandey and Rastogi (2003) stated in their study with 33 chickpea genotypes that the first pod height is essential for chickpeas, but due to climatic conditions, the plant height remained relatively high. Therefore, the first pod height did not increase significantly either. They noted that improving climatic conditions would increase the first pod height. Aarif et al. (2014) emphasized in their study that many traits, including first pod height, are controlled by genetic factors and that this should be given special attention in breeding programs.

Santos et al. (2017) obtained similar results in their genetic diversity study. Aswathi et al. (2019), in their genetic diversity studies with 52 genotypes, stated that genetic factors largely determine the first pod height. In the conducted research, it was observed that environmental factors did not significantly affect the first pod height. This suggests that genetic factors have a strong influence. The results obtained are similar to those of the researchers. Considering this issue in future studies will affect the success of breeding programs.

3.3. Biological Yield

Biological yield is considered one of the critical indicators of plant growth and development, and the growth status of the plant's habitus directly affects the biological yield. Descriptive statistics for varieties regarding biological yield are presented in Table 4. When the table is examined, the highest biological yield value is observed in the İnci variety, 18.40 kg, followed by the Gökçe variety, 15.33 kg. The lowest value is observed in the Azkan variety, which is 7.797 kg. It can be said that the İnci and Seçkin varieties have quite variable characteristics in terms of biological yield. The most stable variety is the Çakır variety. Significantly, the slight variance suggests that it is resistant to variability. Regarding sources of variation, the Seçkin variety is in the first place with 44.32%. The variance analysis for biological yield determined a significant interaction between variety and year, and varieties and years differ significantly (Table 7). It was found that the İnci variety achieved the highest value, while the Azkan variety obtained the lowest value. Looking at the years, the average value for the first year was 14.43, and for the second year, it was 12.12.

The observed difference between them was found to be statistically significant. The significant difference between the years suggests that the year factor should be considered one of the crucial factors determining yield. The interaction's significance indicates that the varieties' environmental responses vary significantly from year to year, directly affecting the yield depending on the conditions.

Table 4. Importance of varieties, years, and interactions according to biological yield

Varieties	Average	Post Hoc
Azkan	7.797±0,65	C
Uzunlu99	13.00±0,95	ABC
Gökçe	15.33±0,85	AB
Seçkin	12.73±1,78	ABC
Hasanbey	15.17±1,31	ABC
İnci	18.40±2,23	A
Çakır	9.125±0,41	BC
Sezenbey	13.11±1,43	ABC
Zuhal	14.70±0,83	ABC
Çağatay	8.940±0,47	BC

In terms of biological yield, it is observed that the Uzunlu 99, Gökçe, Hasanbey, İnci, Sezenbey, and Zuhal varieties have values above the yield average. In contrast, the Azkan, Seçkin, Çakır, and Çağatay varieties fall below the average (Figure 3a). Notably, the İnci variety stands out as significantly above the average, whereas the Azkan and Çakır varieties are notably below the average. Significant differences between the years are observed when examining the changes in the biological yield of the varieties over the years (Figure 3b). The average value is higher in 2021, while lower values are recorded in 2022. This decline in the second year is thought to be determined by the changes in climatic conditions.

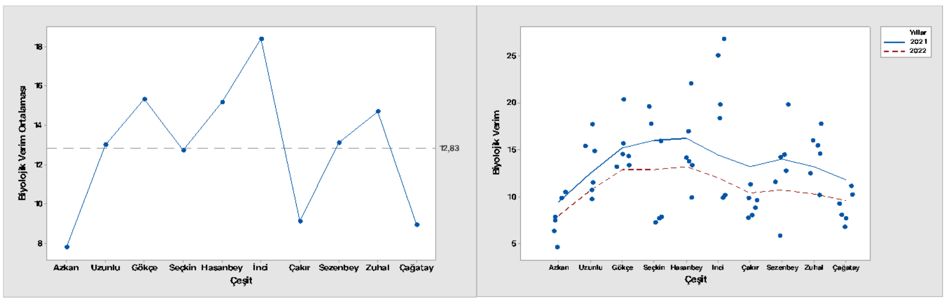

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Figure 3. Distribution of first pod heights around the average and change in biological yield over the years

Pramanik et al. (1990) conducted studies in Bangladesh, indicating that biological yield increases with plant density, but the primary determinant is the variability in environmental conditions. As long as the environmental conditions are conducive to cultivation, there is a tendency for an increase in biological yield. Still, conversely, a decrease is expected in adverse conditions. Akdağ and Şehirali (1995) suggested that increasing the number of plants per square meter is necessary for increasing biological yield, but favourable environmental conditions should support it. Similar conclusions were presented by Khan et al. (2001)

regarding biological yield. Çancı and Toker (2009) stated in their study that temperature changes and drought significantly affect yield and its influencing factors. Agrawal et al. (2018) reported that biological efficiency significantly and positively correlated with grain yield in dry conditions. The unpredicted exacerbation of drought with increasing temperatures is considered especially possible. The recent climate changes indicate that we will face this problem more severely in the coming years. Therefore, we must reconsider our thoughts and plans regarding drought and temperature.

3.4. Number of Pods per Plant

Descriptive statistics for this trait were determined and presented in Table 5. Upon examination of the table, the highest number of pods per plant, 29.33, was observed in the İnci variety, followed by the Hasanbey variety with 25.33. The lowest value, 13.67 pods per plant, was observed in the Azkan variety.

Regarding the number of pods per plant, the Seçkin, Uzunlu, Çağatay, Hasanbey, and Çakır varieties are found to have values above the average number of pods per plant, while the Azkan, İnci, Sezenbey, Zuhal, and Gökçe varieties are below the average (Figure 4a). It is observed that, except for the Sezenbey variety, the varieties below the average significantly diverge from the mean. Among the varieties above the average, Çağatay has shown a distinct divergence behaviour.

Table 5. Importance of varieties, years, and interactions according toThe number of pods per plant

Varieties	Average	Post Hoc
Azkan	13.67±1,42	C
Uzunlu99	19.67±1,54	ABC
Gökçe	21.17±1,09	ABC
Seçkin	19.33±2,58	ABC
Hasanbey	25.33±2,24	AB
İnci	29.33±3,12	A
Çakır	14.50±0,71	BC
Sezenbey	21.50±1,77	ABC
Zuhal	23.50±1,07	ABC
Çağatay	15.00±1,09	BC

When evaluating the varieties by years in terms of the number of pods per plant, it is seen that there is a significant difference between the years (Figure 4b). While the varieties exhibited more stable behaviour in the first year, there was more variation in the second year. Hasanbey and İnci varieties have shown this change more prominently.

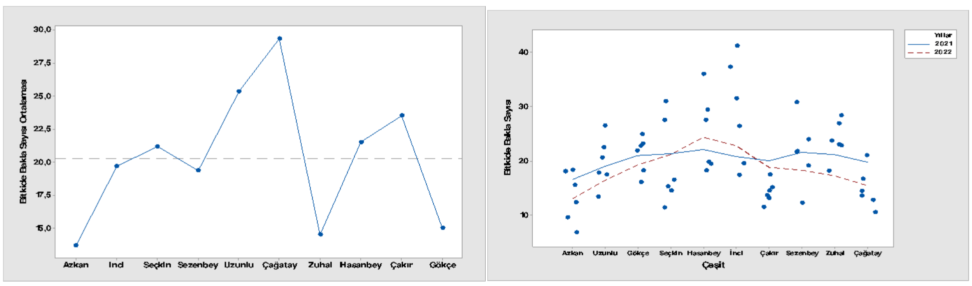

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Figure 4. Distribution of first pod heights around the average and change in the number of pods per plant over the years

The variance analysis results indicate that the variety*year, variety, and year factors are statistically significant for the number of pods per plant. The significance of the variety*year interaction suggests that changes over the years significantly affect the number of pods per plant for different varieties. Environmental factors, especially climatic variations, are thought to play a crucial role in creating these differences. The values obtained in the first year are higher compared to the second year. Therefore, the conditions in the first year were more favourable for plant growth and development than in the second year. Significant differences between the varieties are observed. Especially the İnci and Azkan varieties stand out distinctly compared to others. It is understood that the variations in other varieties are relatively lower. Atta et al. (2008) examined the variation of quantitative traits in chickpea plants. They emphasized that variables, including the number of pods per plant, depend on location, time, and cultivation conditions. Fang et al. (2010) mentioned that water deficits during plant growth and development can adversely affect traits that contribute to yield. Based on the study, climate conditions are the primary determinant of traits influencing yield.

3.5. Number of Seeds per Plant

When the number of seeds per plant for different varieties is examined, it is observed that the highest number is 28.67 for the İnci variety, followed by 23.17 for the Hasanbey variety (Table 6). The lowest value is observed to be 12.0 for the Azkan variety. The analysis results for the number of seeds per plant indicate that the interactions between variety*year and the differences between varieties and years are statistically significant. The significance of the variety*year interaction implies that varieties are significantly influenced by changing environmental conditions from year to year. The high variability between years is considered necessary for indicating the stability of varieties.

Table 6. The number of seeds per plant

Varieties	Average	Post Hoc
Azkan	12.00±1,11	C
Uzunlu 99	20.17±1,02	ABC
Gökçe	22.67±0,96	AB
Seçkin	17.67±1,96	BC
Hasanbey	23.17±1,97	AB
İnci	28.67±2,42	A
Çakır	14.00±0,93	BC
Sezenbey	17.00±2,00	BC
Zuhal	20.33±1,29	ABC
Çağatay	14.33±1,07	BC

According to the average number of seeds per plant for different varieties, it is observed that Uzunlu, Gökçe, Hasanbey, İnci, and Zuhal varieties have values above the average. In contrast, Azkan, Seçkin, Çakır, Sezenbey, and Çağatay varieties fall below the average (Figure 5a). Particularly noteworthy are the deviations of Azkan and İnci varieties from the mean. Seçkin and Zuhal varieties are found to be the closest to the mean. When examined over the years, significant differences between years are observed (Figure 5b). All varieties had higher values in the first year than in the second year. It is noticed that the Azkan variety has the lowest values in both years, whereas the Hasanbey variety has the highest values.

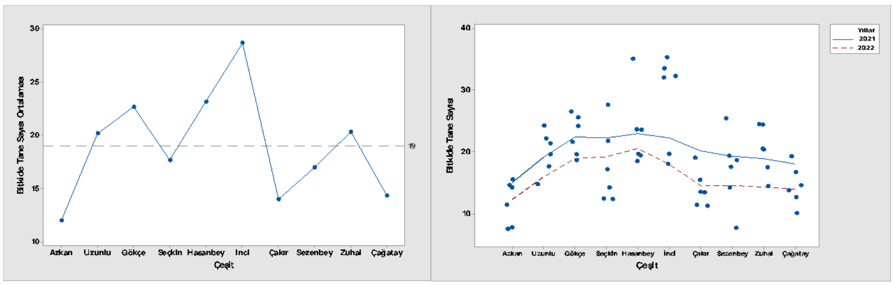

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Figure 5. Distribution of first pod heights around the average and change in the number of seeds per plant over the years

When examining the varieties, it is observed that the İnci variety stands out in Group A, while similarly, the Azkan variety is segregated at the lowest level in Group C. Fang et al. (2011) pointed out that the number of seeds per plant is one of the most sensitive periods during growth and development. Environmental changes during this period can affect seed numbers. Kalefetoğlu and Ekmekçi (2009) stated that during seed maturation in chickpea plants, phytochemical and physiological activities increase, but the primary determinant of these activities is the amount of water in the environment. In the study, the changes observed in all traits in the second year were attributed to the decrease in rainfall compared to the previous year. This explanation aligns with the findings of Kashiwagi et al. (2006), who reported that a reduction of soil moisture negatively affects root development, leading to a decrease in pod and seed formation in plants.

3.6. Seed Yield Per Plant

Descriptive statistics for this trait are provided in Table 7. The highest seed yield per plant was determined to be 8.37 g for İnci, followed by 7.91 g for the Gökçe variety. The lowest value was recorded as 4.26 g for the Azkan variety. It has been determined that Azkan, Seçkin, Çakır, Sezenbey, and Çağatay varieties have values below the average weight of 6.401 g for seed yield per plant. In contrast, Uzunlu, Gökçe, Hasanbey, İnci, and Zuhal varieties are observed to exceed the average value. The deviation of the Azkan and İnci varieties from the average is higher than the others. According to the variance analysis conducted for seed yield per plant, it has been determined that the differences between variety*year, varieties, and years are statistically significant. The average values for the first year (7.23 g) are observed to be higher than those for the second year (6.02 g). Essential changes are observed in the İnci and Azkan varieties, while the others appear similar or close. Considering that Azkan and İnci varieties exhibit similar behaviour in other traits, these results can be regarded as expected.

Table 7. Importance of varieties, years, and interactions according to seed yield per plant

Varieties	Average	Post Hoc
Azkan	4.26±0,42	C
Uzunlu99	7.48±0,53	ABC
Gökçe	7.91±0,41	AB
Seçkin	5.82±0,78	ABC
Hasanbey	7.36±0,53	ABC
İnci	8.37±0,89	A
Çakır	4.79±0,14	BC
Sezenbey	6.19±0,81	ABC
Zuhal	7.14±0,54	ABC
Çağatay	5.10±0,31	ABC

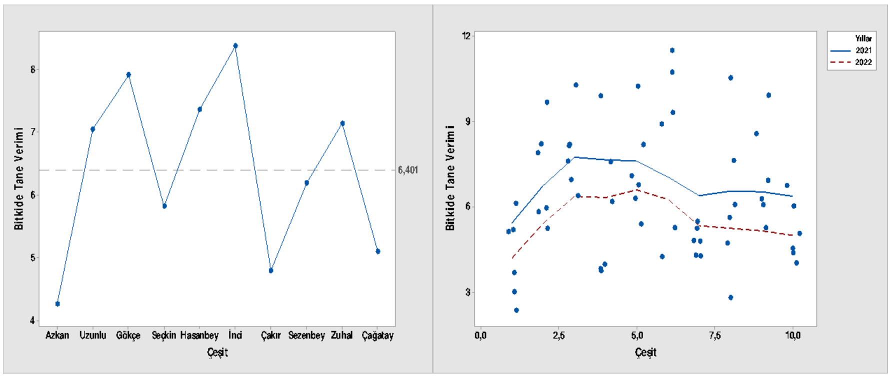

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Figure 6. Distribution of first pod heights around the average and change in seed yield per plant over the years

Shrestha et al. (2006) examined the physiology of seed yield and emphasized that environmental conditions significantly influence yield more than genetic factors. They noted that soil water deficiency directly impacts seed yield, drastically reducing seed weight under insufficient water conditions. Fogelberg and Martensson (2021) highlighted that factors such as soil properties and nutrient adequacy play crucial roles in plant productivity beyond the characteristics of varieties. They suggested that suitable soil conditions are essential for plants to achieve their potential yield. Slafer et al. (2009) indicated that environmental conditions and genetic control should be considered together to enhance plant yield. Our study observed that the yield per plant significantly decreased in the second year compared to the first year. Poor rainfall distribution during the growing season adversely affected plant growth and development, hindering seed maturation and reducing seed yield.

3.7. Hundred Seed Weight

One of the determinants of yield is hundred seed weight, where the desired size of seeds can only be achieved under suitable environmental conditions. Descriptive statistics for this characteristic are presented in Table 8. While differences among varieties are statistically significant, years and variety*year interaction are insignificant. Sezenbey, Çağatay, Azkan, Çakır, and Uzunlu varieties are grouped, while İnci variety stands apart from the others. The highest hundred seed weight value, 36.37 g, was observed in the Sezenbey variety, followed by 35.91 g in the Çağatay variety. The lowest value, 28.67 g, was observed in the İnci variety.

Table 8. Importance of varieties, years, and interactions according to 100 seed weight

Varieties	Average	Post Hoc
Azkan	35.70±0,88	A
Uzunlu99	35.01±1,37	A
Gökçe	34.90±0,94	AB
Seçkin	32.34±1,12	AB
Hasanbey	32.07±1,08	AB
İnci	28.67±0,93	B
Çakır	35.52±1,40	A
Sezenbey	36.37±1,02	A
Zuhal	34.96±0,74	AB
Çağatay	35.91±0,73	A

When we look at the distribution around the mean of hundred-seed weight, Çakır, Uzunlu, and Zuhal varieties are below the average, with Zuhal notably diverging (Figure 7). On the other hand, Sezenbey, Çağatay, Azkan, Gökçe, Seçkin, Hasanbey, and İnci varieties are above the average, showing no significant deviation from the mean value. Examination of the variation in hundred-seed weight over the years reveals no significant differences. The average for the first year was 35.31 g, whereas for the second year, it was 35.34 g.

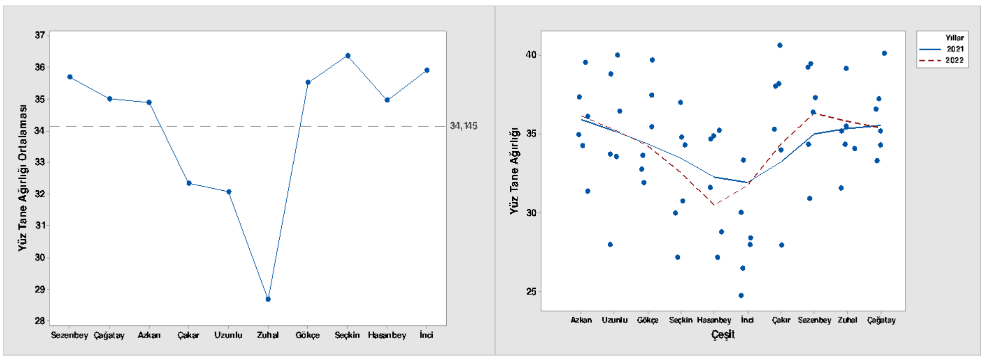

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Figure 7. Distribution of first pod heights around the average and change in 100 seed weight over the years

Dua (1992) emphasized that excessive chloride levels in the environment are highly affected by chickpea genotypes, which can limit plant growth and development. Increased chloride levels due to salinity in dry areas could negatively impact yield and yield-related traits, warranting caution. Aswathi et al. (2019) highlighted significant variations in morphological and biometric characteristics among 52 genotypes, emphasizing that seed-filling periods are critical. Notably, the high hundred-seed weight indicates successful seed filling, hence requiring special attention. In our study, the weight of the hundred seeds varied among varieties but showed no significant changes across the years. Therefore, it can be concluded that the overall condition of the soils where cultivation is carried out is suitable for chickpea farming. Maintaining acceptable salinity levels also ensures that chloride does not directly harm plants.

3.8. Harvest Index

Harvest index, considered a significant yield indicator, exhibited considerable variability among varieties. The highest harvest index value was observed in Çağatay variety at 56.94%, followed by Uzunlu 99 at 54.48%. The lowest value was recorded in the İnci variety at 46.29% (Table 9).

Table 9. Importance of varieties, years, and interactions according to harvest index

Varieties	Average	Standard Deviation
Azkan	54.26±1,81	5.74
Uzunlu99	54.48±1,62	5.13
Gökçe	51.67±0,86	2.72
Seçkin	46.67±1,62	5.14
Hasanbey	49.02±0,86	2.74
İnci	46.29±1,49	4.73
Çakır	53.01±1,64	5.19
Sezenbey	46.69±1,31	4.13
Zuhal	48.37±1,54	4.88
Çağatay	56.94±0,98	3.14

In terms of harvest index, Azkan, Uzunlu, Çakır, and Çağatay varieties were observed to exceed the average index value of 50.74 (Figure 8). Conversely, Seçkin, Hasanbey, İnci, Sezenbey, and Zuhal varieties fell below the average. Çağatay variety surpassed the average, whereas the İnci variety deviated below the average. Similar to other traits, the variability observed among varieties is generally attributed to environmental factors that shape genetic characteristics. When examining various responses across years, no statistically significant differences were observed between years. Upon reviewing the movement of curves, it can be seen that they exhibit similar patterns. Although changes were observed across years in harvest index values, these variations did not lead to significant differences.

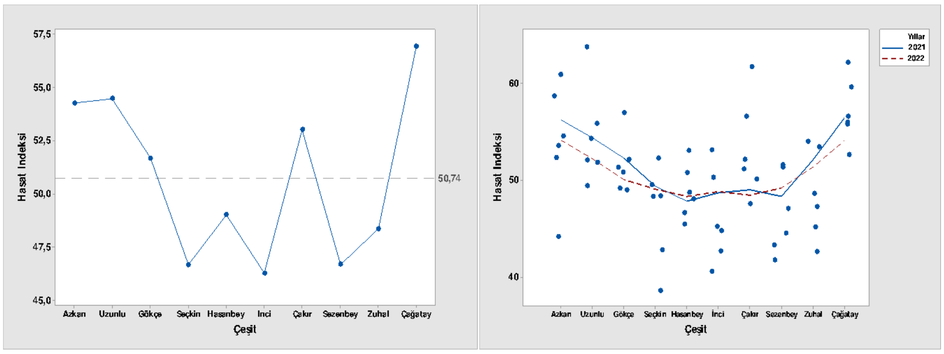

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Figure 8. Distribution of first pod heights around the average and change in harvest index over the years

In the study, significant differences were observed among varieties, while years and the interaction between year and variety were found to be insignificant. The lack of significance of years could indicate that varieties exhibit similar responses in terms of harvest index across different years. Additionally, the insignificance of interaction suggests that variations among varieties across years are not substantial enough to create significant differences, indicating stability in this trait.

Mohammed et al. (2015) stated that the harvest index is a crucial determinant for yield-related traits in chickpeas when conducting their study to ascertain genetic variability. They emphasized that the harvest index is mainly associated with traits such as plant height and seed filling, urging attention to these factors in future research. Additionally, Sohail et al. (2018) indicated that chickpeas' relationships among yield and yield-related traits are primarily genetic, with high heritability estimates. Akhtar et al. (2011) determined that the extent of inter-trait relationships influences the effects of yield-related traits. The conducted study supports that harvest index is notably correlated with traits such as plant height, first pod height, pod number per plant, and seed number per plant. However, the high genetic correlation between these traits will remain a fundamental determinant.

3.9. Seed Yield

Significant differences were observed when evaluating varieties for seed yield per hectare (Table 10). The highest seed yield was obtained from the Gökçe variety, with 124.51 kg/ha, followed by the Çakır variety, with 118.92 kg/ha. The lowest seed yield value was observed in the Azkan variety, with 82.71 kg/ha. Considering the Azkan variety's consistently lower values across all examined traits, this outcome was anticipated. In terms of overall yield levels, Azkan, Seçkin, Hasanbey, and İnci varieties have been observed to exhibit values below the average yield. In contrast, Uzunlu 99, Gökçe, Çakır, Sezenbey, Zuhal, and Çağatay varieties have shown yields above the average. However, Uzunlu 99 (103.27 kg/ha), Sezenbey (103.43 kg/ha), and Zuhal (103.61 kg/ha) varieties have yields very close to the average yield of 102.83 kg/ha. Analysis of yield values across years reveals that the first year (112.78 kg/ha) had a significantly higher yield than the second year (99.97 kg/ha). This difference is attributed to the adverse environmental conditions prevailing in the second year, negatively impacting all traits. Among the varieties, Gökçe stands out distinctly with the highest value, while Azkan also significantly differs from other varieties due to its lower yield performance.

Table 10. Importance of varieties, years, and interactions according to seed yield

Varieties	Average	Standard Deviation
Azkan	82.71±3,49	11.05
Uzunlu 99	103.27±4,36	13.80
Gökçe	124.51±2,87	9.07
Seçkin	88.92±4,33	20.08
Hasanbey	97.72±3,14	9.94
İnci	95.63±4,17	16.36
Çakır	118.92±3,73	14.95
Sezenbey	103.43±3,72	11.77
Zuhal	103.61±3,07	9.71
Çağatay	109.57±3,11	9.82

Saeed et al. (2012) determined that the traits influencing yield significantly impact yield. Therefore, they suggested that evaluating yield based on individual characteristics and considering all components would provide a better assessment. Yadav et al. (2001) emphasized that understanding the traits associated with seed yield is essential for accurately defining yield potential. Palta et al. (2005) stated that besides traits influencing yield, plant nutrients also play a crucial role in determining seed yield. They highlighted that inadequate plant nutrients can decrease seed protein content, thereby reducing yield. The conducted study identified that traits associated with yield are effective. These traits are particularly influential during variable climatic conditions (Nayak and Altekar, 2015).

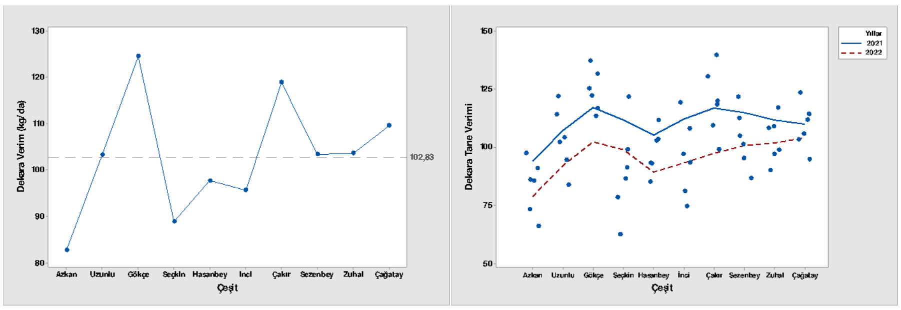

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Figure 9. Distribution of first pod heights around the average and change in seed yield over the years

4. Conclusions

Ecologically, environmental conditions are always fundamental in shaping and influencing factors affecting yield. Variations occurring within the same year can be influential, while differences between years can also be decisive. Breeders conducting breeding programs aim to identify genotypes least affected by changes in environmental conditions and exhibiting high stability. However, achieving this is highly challenging and time-consuming, yet necessary. Studies involving environmental conditions can consider years as ecological factors, and they can also investigate environmental effects by taking different locations within the same year. In this study, changes over the years have been examined. Overall, it has been observed that varieties show significant responses to changes in climate. The significance of variety, year, and variety-year interactions indicates that environmental conditions strongly influence genetic factors. The Gökçe variety has generally exhibited successful performance in yield and yield-affecting traits, consistently ranking high. It can adapt better to changing environmental conditions than other varieties. In contrast, the Azkan variety's generally low performance in yield and yield-affecting traits indicates its weak tolerance to changing environmental conditions. When looking at the long-term average, there is no serious change in humidity, while the temperature has increased by 3.5-4.0 degrees. If the necessary precautions are not taken, it can be expected to increase a little more. It is seen that the amount of precipitation has decreased significantly with the increase in temperature. The fact that it has decreased by about half in 2022 and more than half in 2023 is worrying for the future, and also poses a problem in terms of plant cultivation. It can be said that chickpea plants have difficulty in showing their real yields in these locations. Considering that conditions will become a little more difficult in the future, it will be beneficial to grow drought-resistant varieties instead of drought-tolerant varieties. Additionally, while the Çakır variety typically received low values except for the hundred seed weight and harvest index, it showed good performance in terms of yield. According to the study, it is understood that varieties show differences in stability. Particularly under changing ecological conditions, such studies provide valuable insights for the future.

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Research Article

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Profitability of Poultry Egg Farming in Rivers State, Nigeria

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HIGHLIGHTS

- Poultry egg farming demonstrates significant profitability, with a monthly gross margin of ₦368,457.91 and net farm income of ₦325,957.91. t
- For every ₦1 invested, farmers achieve ₦0.49 gross margin returns and ₦0.46 return on investment, highlighting the enterprise's economic viability.

Abstract

Maximizing profit is one of the major aims of business ventures and is obviously and largely reliant on how proficient and efficient resources, especially finance, are utilized. Hence, this research examined the profitability of poultry egg farming in Rivers State, Nigeria. The research depends on primary data collected using questionnaires and interview schedules from 120 poultry egg farmers using multistage sampling procedures. Descriptive statistics, ordinary least squares (OLS) regression model, and cost and returns analysis were employed to analyze the data collected. Analysis revealed that the majority (60.8%) of the farmers were males, and the majority (82.5%) were married. The mean age of the farmer was 44.69 years, with about 38.3% of them taking poultry egg farming as their primary occupation. The study showed that stock size, labor, and feed cost were statistically significant at 1% in the enterprise's profitability. The research indicates that poultry egg farming is profitable, as specified by the gross margin of ₦368,457.91 and a net farm income of ₦325,957.91 per month with all the respondents selected. The profitability ratios show that for every ₦1 invested in poultry egg farming, the farmer can earn ₦0.49 as gross margin returns, ₦0.46 as return on investment, and ₦0.30 as net profit ratio. The research, therefore, recommends that females and youths should be encouraged to engage in poultry egg farming; extension agents should also aim to increase farmers' knowledge of efficient utilization of financial resources to improve profitability.

Keywords: Poultry egg; Cost and return; Profitability ratios; Gross margin; Nigeria

1. Introduction

Agricultural operations remain central to the Nigerian source of economic growth, reduction of poverty, contribution of gross domestic product (GDP), job opportunities, and income generation (Philip et al. 2009). Agriculture is essential among the major sections of the economy; agriculture employs above 60% of the working population using contributions from livestock, crops, forestry, and fisheries; it contributes approximately 42% to GDP (CBN 2007). Livestock production forms a crucial and fundamental segment of the agricultural sector economy of Nigeria; a form that stretches further than absolute food productivity

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conversely integrates employment generation, source of revenue and livelihood to farmers, economic growth and development of the nation, and source of several multiuse purposes. The poultry production segment is very significant in the livestock sector of agricultural production, including chickens, ducks, and turkeys. However, chickens single-handedly comprise about 95% of poultry farming globally (Kallaet al. 2007). Poultry productivity is distinctive, as it proffers a maximum turnover ratio and the fastest returns to investment cost regarding the livestock farming business (Sanni and Ogundipe 2005). Poultry production has remained and is recognized as the quickest and most vivacious way of resolving the challenge of protein inadequacy in the Nigerian diet (Akpabio et al. 2007). Poultry farming is unique; it possesses a high level of feed conversion rates and minimum price and is a preeminent supplier of animal protein.

Poultry production in Nigeria presently is approximately 10% of the population and accountable for between 15-18% of job opportunities, as a result of the reality that the poultry enterprise is majorly small-scale in practice (Afolami et al. 2011), as compared with other animal products such as beef, pork, ham among others, poultry egg is further regarded to be more tasty and edible, cheap in cost, possessing low cholesterol level with high protein content (Odimegwe et al. 2015). However, one of Nigeria's main difficulties is the satisfaction of the constantly increasing requirement for protein. The majority of Nigerian diets are inadequate in animal protein. Egg poultry production product contributes approximately 3.5g of the whole 7.2g of the animal protein demanded for an individual daily nutritional needs. For developing nations like Nigeria, poultry supplies approximately 15% of the aggregate animal protein consumption, with just about 1.3kg consumed annually per individual. (NLDC 2000). The World Health Organization (WHO) and Food and Agriculture Organization (FAO) recommended that poultry products be consumed by about 3.6 kg per capita annually. The consequences of not meeting these protein requirements are widespread hunger, poor nutrition, stunted growth, and disease epidemics evident in the country. Consequently, to meet the essential lowest amount requirement of the nutritional protein requirements of Nigerians, the nation needs yearly production of 10-20 billion eggs and 0.3-0.6 million tons of poultry meat as reported by NLDC (2000).

Poultry eggs and meat are beneficial in bridging and straddling the protein gap Nigerians require. Generally, poultry eggs are agreeable and suitable; this agreeability and suitability cuts across virtually all sociocultural and religious borderlines in Nigeria. The value of poultry production to the nationwide economy cannot be overstated, as it remains a popular enterprise for small-scale farmers with small owners who have enormous influence and contribution to the country's economy. Poultry egg production has assumed better significance in enhancing job prospects and animal protein production requirements in the country.

To this intention, knowledge on profitability and productivity in the enterprise should be an up-to-date issue that has a sustainable means of bridging several knowledge gaps and aiding in articulating accurate policies intended to enhance the increase in profitable poultry egg farming in the nation. Therefore, this research examined the profitability of poultry egg farming, determined the net profit ratios and gross margin returns; and determined the rate of return on investment in poultry egg farming in the sampled area.

2. Materials and Methods

The study was conducted in two agricultural zones in Rivers State, Nigeria. The two zones were considered most suitable due to the heavy concentration of poultry farming, specifically layers' production. The State lies between longitude 7°00'E and Latitude 5°70', which covers an area of 11,077km^2 (NDRDMP 2006). The neighboring States towards the north side are Imo, Abia, and Anambra State, while the State towards the east side is Akwa/Ibom State, and the State towards the west side is Bayelsa State. Towards the south side, it is bordered by the Atlantic Ocean (RSADP, 2008). The dried highland part of Rivers State covers. The drier upland region of Rivers State embodies about 61% of the total land area, whereas the riverine parts with an alleviation range of 2-5m occupied about 39% (RSADP 2008). The population of the State stands at 5,198,716 based on the NPC (2006). Major food crops grown include yam, cassava, maize, and vegetables; cash crops grown include oil palm, rubber, coconut, banana, and plantain. Livestock reared in the State include poultry, pigs, goats, and fish. The poultry bird reared includes laying birds for eggs, broilers, cockerels, and turkeys.

Multistage sampling procedures were utilized. First, six Local Government Areas (LGAs) were selected using a simple random method; namely Oyigbo, Obio/Akpor, Emohua, Ikwere, Etche, and Eleme LGAs. Four communities in each LGA were selected using the simple random method, making twenty-four communities. Thirdly, five poultry egg farmers were selected using a simple random method from the chosen communities, which gave an aggregate of one hundred and twenty poultry egg farmers. Data were garnered by utilizing a questionnaire and interview schedule. Descriptive statistics and inferential such as ordinary least square OLS, net profit ratios, and gross margin were employed to analyze the data garnered.

Specification of Model:

$$\pi = TR - TC \quad (1)$$

Where;

π is the net profit
TR is the total revenue
TC is the total cost

$$GM = TR - TVC \quad (2)$$

Where;

GM is the gross margin
TR is the total revenue
TVC is the total variable cost

The OLS regression function model was utilized to examine the factors influencing profitability. The explicit form of the profitability model is specified thus:

$$\pi = \beta_0 + X_1\beta_1 + X_2\beta_2 + X_3\beta_3 + X_4\beta_4 + X_5\beta_5 + X_6\beta_6 + \varepsilon \quad (3)$$

π = profit (₦)
X_1 = Total cost of renting pen (₦)
X_2 = Stock size (number of laying birds)
X_3 = Labour/salary cost (₦)
X_4 = Total cost of feed (₦)
X_5 = Total cost of drugs (₦)
X_6 = Total cost of transportation (₦)
ε = Error term
β_0 = Constant
β_1 - β_6 = Coefficients of variables

The theory behind Cost and Return and OLS Regression

The output level that maximizes profits may be ascertained using the cost-return relationship. By examining the point at which marginal revenue equals marginal cost (MR = MC), businesses aim to maximize their profits because producing more would result in lower earnings (Frank and Bernanke 2013). This connection can help businesses make decisions about production, resource allocation, and strategic planning to maximize productivity and profitability.

OLS regression assumes that one or more independent variables, X1, X2, …, X6, and the dependent variable, π, may be modeled (Koutsoyiannis 2003), as shown in equation (3). In this case, the error term is ̥, the independent variable coefficients are $\beta_1, \ldots,$ and the intercept (constant) is β_0. To minimize the sum of squared residuals (differences between observed and predicted values), OLS looks for values of β_0, $\beta_1 \ldots$, β_6. Moreover, observations are independent, and there is a linear connection between the independent and dependent variables (Koutsoyiannis 2003; Gujarati and Porter 2009). Therefore, the OLS regression model implies a linear connection between profitability and different factors for examining the profitability of chicken egg production.

3. Results and Discussion

The socioeconomic characteristics of the poultry egg farmers are shown in Table 1:

Table 1. Socioeconomic characteristics distribution of the poultry egg farmers

Variables	Frequency	Percentage
Age		
25 and below	4	3.3
26 – 35	21	17.5
36 – 45	35	29.2
46 – 55	42	35.0
56 and above	18	15.0
Mean	44.69	
Gender		
Male	76	60.8
Female	47	39.2
Marital Status		
Single	21	17.5
Married	99	82.5
Occupation		
Poultry as a primary occupation	46	38.3
Poultry as a secondary occupation	74	61.7
Stock size (number of laying birds)		
1000 and below	51	42.5
1001 – 2000	39	32.5
2001 – 3000	17	14.2
3001 – 4000	7	5.8
4001 – 5000	3	2.5
5001 and above	3	2.5
Mean	1635	
Annual Income (in Million naira)		
1 and below	31	25.8
1.1 – 5	80	66.7
5.1 – 10	5	4.2
10.1 and above	4	3.3
Mean	2681930.00	

Table 1 shows that 35.0% of the poultry egg farmers' age ranges from 46 – 55 years and about 29.2% range from 36 – 45 years, agrees Henri-Ukoha et al. (2011) found that age bracket of about 31 to 50 years active, objective and interested individuals in farming among small-scale farmers in Abia State Nigeria. While the mean age is 44.69 years, this agrees with Tibi and Adaigho (2015), who found 46 years among small-scale poultry farmers in Delta State, Nigeria. The implication of these findings about age implies that a more significant number of those participating in poultry egg production were within the middle age which was the workforce, strong enough to undertake vigorous and strenuous activities associated with poultry farming. About 60.8% of the respondents were males. This explains the age-long tradition confirming that men are breadwinners and must provide for their households. About 82.5% were married, which is in agreement with Tibi and Adaigho (2015), who discovered that 78.3% of small-scale poultry farmers in Delta State, Nigeria, were married. About 38.3% took poultry farming as their primary occupation, this agrees with Fakhrul et al. (1999) who found out that about 10% considered poultry production to be the primary occupation in the Gazipur district of Bangladesh. The majority (42.5%) of stock are less than 1000 laying birds with a mean of 1635, and this implies that most of the poultry egg farmers were small-scale poultry farmers. About 66.7% of the egg poultry farmers have annual income ranges from ₦1,100,000.00 – to ₦5,000,000.00, this implies that the enterprise despite the high risk is still profitable.

Table 2. OLS Regression results of profitability of poultry egg farming

Variables	Coefficient	Standard error	t-values	Sig. levels
Constant	19111.250	28615.802	0.668	0.506
Cost of renting pen (₦)	0.253	0.196	1.293	0.199
Stock size (number of birds)	107.589	31.864	3.377	0.001***
Labour/salary cost (₦)	5.797	1.306	4.438	0.001***
Cost of feed (₦)	-0.221	0.056	-3.958	0.001***
Cost of drugs (₦)	-0.457	1.319	-0.346	0.730
Transportation cost (₦)	0.051	1.976	0.026	0.979

R = 0.821; R-squared = 0.674; Adjusted R-squared = 0.656; Standard Error = 172421.2469; Observation = 120; df = degree of freedom

Source: Field Survey 2018

From Table 2, the R-value of 0.821 signifies a good point of likelihood. The coefficient of the determinant factor of the relationship of variance in the dependent variable expounded by the explanatory variable, which is the R-squared; the value of 0.674 was obtained, which shows that independent variables explain 67.4% of the changeability of the dependent variable (profitability). This implies that 67.4% of the variation that occurred in the dependent variable has been elucidated and described by the explanatory variables, such as stock size (X_2), labour/salary cost (X_3), and cost of feed (X_4), and that the remaining 32.6% was as a result of the random variable. The findings show from Table 2 that out of the six variables analyzed, only three were statistically significant at 1%, affecting the profitability of the poultry farmers in their enterprise. Stock size (number of laying birds), labour/salary cost, and feed cost were statistically significant at 1%.

Profitability is positively impacted by a high statistical significance (p = 0.001) and a stock size (number of birds) coefficient of 107.589. This outcome is consistent with the findings of Oke (2024), who discovered that stock size is a significant factor influencing profitability. Larger chickens frequently result in lower expenses per unit and higher total sales. According to similar results from research conducted in Ghana by Wongnaa et al. (2023), increasing stock size maximizes resource utilization and boosts productivity.

The significantly significant labour/salary cost coefficient of 5.797 (p = 0.001) indicates that labour investment boosts profitability. This aligns with the findings of Oke (2024), who discovered a favorable correlation between labour costs and farm profitability in Nigerian poultry. The health and egg output of birds are often improved by skilled work. Kibunja and Musau (2024) also discovered that Kenyan farms that invested in trained workers saw increased production, confirming that labour costs and profit in chicken farming are positively correlated.

With a coefficient of -0.221, the feed cost harms profitability and is highly significant (p = 0.001), suggesting that greater feed costs translate into lower earnings. This is consistent with Jacob et al. (2014) and Oke (2024), who showed that feed costs were the most significant expense in chicken production and directly affected profitability. Similar patterns are reported by Ugochukwu and Uzoma (2019), who highlight the significance of cost-effective feed supply for preserving profit margins by describing how feed cost variations pose significant risks.

According to the model, the three main factors influencing profitability are feed cost, labour cost, and stock size. In line with findings from related research conducted throughout Nigeria and West Africa, high feed prices lower profitability while the stock size and labour expenses increase it. This implies that increasing operations and investing in competent workers while controlling feed costs are essential for raising chicken egg farming's profitability.

Table 3. ANOVA profitability in poultry egg farming

Model	Sum of squares	df	Mean square	F-value	Sig. level
Regression	6.932×10^{12}	6	1.155×10^{12}	38.860	0.001***
Residual	3.359×10^{12}	113	2.973×10^{10}		
Total	1.029×10^{13}	119			

df = degree of freedom
Source: Field Survey 2018

The F-ration in the Analysis of variance (ANOVA), as shown in Table 3, is whether the whole regression model is a worthy measure of the data. It shows from the Table that the explanatory variables were significantly statistically envisaged the dependent variable, $F(6,113) = 38.860$, $p = 0.000$, hence, the regression model is a worthy measure of the data. F-value 38.86 showed that all explanatory variables significantly affect the dependent variable (profit). Since the p-value of 0.000 was obtained, which is less than 0.01 ($0.000 < 0.01$) at the significance level, it means that, overall, the regression model statistically significantly predicts the outcome variables. This implies that poultry eggs are profitable as a business and source of livelihood.

Table 4. Estimation of cost and returns of poultry egg production

Variables	Mean quantity	Unit cost (₦)	Mean values (₦)	Percentage
Value of eggs	1260	850.00	1,071,000.00	
Variable cost				
Cost of drugs			19,784.80	2.7
Cost of feeding			642,361.46	86.2
Cost of labour			28,958.33	3.9
Cost of transportation			11,437.50	1.5
Total variable costs			702,542.09	
Cost on rent			42,500.00	5.7
Total fixed cost			42,500.00	
Total cost			745,042.09	100
Gross margin			**368,457.91**	
NFI			**325,957.91**	
ROI			**0.46**	
GMR			**0.49**	
NPR			**0.30**	

Note: NFI = net farm income; ROI = return on investment; GMR = gross margin returns; NPR = net profit ratio
Source: Field Survey 2018

Table 4 shows the cost return and profitability estimation of poultry egg farming. It shows that the poultry business is profitable, with a gross margin value of ₦368,457.91 and a net farm income of ₦325,957.91 per month. The total revenue from sales of eggs was ₦1,071,000.00. Feeding the poultry birds is the highest (86.2%) cost incurred by the farmer out of the overall costs. This agrees with Ashagidigbi et al. (2011), and Odimegwe et al. (2015) found that the feeding cost of the laying poultry was more than 70% of the overall cost incurred during the production of eggs in Osun State and Ogun State in Nigeria, respectively. The estimation of profitability ratio shows that at any time ₦1 is spent on poultry egg farming business, a farmer earns ₦0.49 as gross margin, a ₦0.46 net income as return on investment, and a gross revenue of ₦1.44 as return on capital employed on the business, with net profit ratio of ₦0.30 is definite as net profit for every single ₦1 exchange for egg at the farm gate. This finding agrees with Odimegwe et al (2015), who reported ₦0.30 net profit ratio and ₦1.43 return on capital employed in their study in Ogun State Nigeria, among poultry farmers.

4. Conclusion and Recommendations

It is established from the research that the poultry egg farming business in Rivers State was profitable even though the majority (60.8%) were male, with about 82.5% married and an average age of 44.69 years. About 38.3% took poultry farming as the primary source of livelihood, this shows that the majority were part-time or took poultry egg farming for leisure, despite this, the average stock size was 1635 with an average annual income of about ₦2,681,930.00. OLS regression analysis revealed that stock size (number of laying birds), labor/salary cost, and feed cost were statistically significant at 1%. The gross margin of about ₦33,390,950.00 and a net income of about ₦28,290,950.00 per month prove that the poultry enterprise is profitable. In addition, the profitability ratios reveal that whenever ₦1 is spent on the production of eggs, there is a prospective revenue of ₦0.30 net farm income. The study further revealed that the profit rations gotten were highly more significant than the rate of interest on agricultural credit or loan of about 8% as well as higher than the mean interest rate on commercial credit or loan of about 21%, which implies that the poultry egg farming is highly viable and profitable.

The study, therefore, recommends, among others, that if more people, particularly females, and youths, be encouraged to participate in poultry egg farming, this shall make eggs available for consumption and create employment opportunities. Also, if farmers were more proficient in utilizing financial resources, they would likely earn more revenue from every naira spent in producing poultry eggs. Furthermore, extension agents should aim to increase the farmers' knowledge of how to effectively utilize the financial resources in such a way as to enhance the farmers' profit. Furthermore, feed accounts for a sizeable portion of the overall production expenses in poultry farming. Policies that give feed subsidies or discounts for large purchases can assist farmers in lowering these costs. The government or agricultural cooperatives may make this possible through alliances with feed providers. It is essential to guarantee consistent demand and reasonable prices. Farmers may be shielded from market volatility by policies establishing reliable distribution networks, connecting them to regional and local markets, and enabling price floors for eggs. Creating farmers' groups or cooperatives may also give you more negotiating leverage.

Conflicts of Interest: The author has not declared any conflict.

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Research Article

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Magnetic Field Effect on Seed and Crude Oil Yields in Mustard (*Brassica Campestris*)

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HIGHLIGHTS

- Magnetic field seed treatment increases mustard yield in the field.
- The effect of the magnetic field treatment varies depending on the exposure time.
- The responses to the magnetic field application varied among the mustard varieties.
- Sustainable, cheap and easy treatment for increasing productivity has been proposed.

Abstract

Mustard (*Brassica campestris*) is an important spice and oil plant. Seed yield and oil quality of mustard vary depending on genetic, ecological, morphological, physiological, cultural, and environmental factors and their interactions. Increasing obtained seed or oil yield as the final product is of great economic importance. One of the innovative and environmentally friendly methods for increasing the efficiency and quality of plant production is magnetic field applications. Mustard varieties 'Tori' and 'Sarson' were used in the study to reveal their performances under the effect of magnetic field (MF) treatments. The 'Tori' and 'Sarson' seeds were exposed to 150 mT MF strength for different periods (0-control, 24, 48, and 72 hours). The highest seed and crude oil yields were obtained in 24-hour-MF treatment as 165.18 kg da^{-1} and 58.97 kg da^{-1}, with an increase of 43.39% and 38.72% according to the control treatment in the 'Tori' variety. In the 'Sarson' variety, seed and crude oil yields were recorded as 210.39 kg da^{-1} and 78.9 kg da^{-1}, respectively, with an increase of 54.03% and 44.4% according to control in 48-hour-MF treatment. This study reveals that MF treatment increased seed and crude oil yields in mustard, and the protocol could significantly contribute to the yields of other crop plants.

Keywords: Mustard; Magnetic field; Crude oil; Seed yield

1. Introduction

Against the rapidly increasing world population, food production is not growing at the same rate, and this shows that in each passing day, more and more people will be in danger of hunger and malnutrition. It is impossible to increase crop production areas to meet the growing needs of the world's food supply. The only way to increase plant production and yield is to increase the quantity of products obtained from the

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unit area. The fact that the interventions are environmentally friendly and renewable is among the important issues emphasized recently (Aboelazayem et al. 2018).

The economic independence of a country is directly proportional to energy source (Aslan and Eryilmaz 2020). From this point, the leading economic expenditure in production could be reduced with ecologically compatible renewable energy systems. Increasing the yield and quality obtained in agricultural output to the maximum level with environmentally friendly and sustainable methods is the aim for today and in the future. The application of seed priming methods by farmers in agricultural production can be successful as an alternative to chemical inputs (Oğuz et al. 2023). Inexpensive and environmentally friendly alternative sustainable methods will be preferred by the farmers when the increasing costs of chemical inputs are considered. Elimination/minimizing of chemical inputs in agriculture is highly important in achieving the "Sustainable Development Goals". Different seed preparation methods are known to increase plant performance effectively (do Espirito Santo Pereira et al. 2021). Seed preparation studies aim to maintain product yield sustainably and economically.

Brassicas are members of the *Brassicaceae* (*Cruciferae*) family (Rahman et al. 2018). *B. nigra* (2n = 16), *B.campestris* (2n = 20), *B. carinata* (2n = 34), *B. juncea* (2n = 36) and *B. napus* (2n = 38); are some of the important species (Hassan 2015; Kayaçetin et al. 2018). The *Brassica* family includes species with high oil and protein content. In addition; there are a wide variety of plant groups grown as vegetables, feed, and spices (Başbağ et al. 2010; Spragg 2016; Cartea et al. 2019). Mustard seeds have a high oil content of about 24-40%. Due to its high oil content, it is important in terms of vegetable oil and biodiesel production in the world (Başbağ et al. 2010; Al Snafi 2015; Aslan and Eryilmaz 2020). Seed yield and oil quality of mustard vary depending on genetic, ecological, morphological, physiological, cultural, and environmental factors and their interactions (Kayaçetin et al. 2018; Cartea et al. 2019). Increasing the seed or oil yield obtained as the final product is of great economic importance in mustard.

One of the innovative and environmentally friendly methods in increasing the efficiency and quality of plant production is magnetic field (MF) treatment. MF treatment enhances vegetative growth by influencing seeds' physiological and biochemical processes. It also improves product yield and quality (Pietruszewski and Martínez 2015; El-Gizawy et al. 2016; Beyaz et al. 2020; Aslan and Eryilmaz 2020). Many scientists have studied the positive and negative biological effects of MFs on living organisms. MF exposure to various plant species could result in different biological effects (Bilalis et al. 2013; El-Gizawy et al. 2016). MF treatment improved yield parameters and stress tolerance in many plant species such as sunflower (Matwijczuk et al. 2012), maize (Vashisth and Joshi 2017), potato (Bahadir et al. 2020), and sorghum (Beyaz et al. 2020) and barley (Okumuş et al. 2023). Most of the MF applications have been tested in laboratory trials. These studies mostly target the early stages of plant development, such as germination and seedling growth. Testing plant yield and yield parameters in field conditions is of great importance in determining the success of the treatment. Undoubtedly, the results will contribute to MF studies and new strategies (Pietruszewski and Martínez 2015).

In this study, an alternative method was investigated to increase mustard yield. It is the first study to determine the effects of MF seed treatment on yield parameters under field conditions in mustard. In this context, the aim was to determine the impact of different exposure times of 150 mT strength MF on seed and crude oil yields in the 'Tori' and 'Sarson' varieties.

2. Materials and Methods

This study was conducted in 2018 and 2019 in experimental fields of the Faculty of Agriculture, Ankara University. The study site was 860 meters above sea level. It was between 39° 57' north latitude and 32° 52' east longitude (Çatak 2019). The seeds of varieties 'Tori' and 'Sarson' were used in the study.

Analyzing soil samples belonging to the trial field was conducted at Ankara University, Faculty of Agriculture, Department of Soil. According to the analysis results, soil samples have pH 7.37, water saturation 61%, total salt 0.042%, quicklime (CaO) 5.66%, total N content 0.145%, phosphorus (P_2O_5) 5.52 kg da^{-1}, potassium (K_2O) 192 kg da^{-1} and organic compounds (1.05%).

2.1. Magnetic Field Generation & Treatment

The magnetic field system was established according to the protocol of Tanaka et al. (2010) with some modifications. Sintered magnets Nd-Fe-B banded N35 Atech, Beijing, China (https://www.atechmagnet.cn/) were used in the study. These magnets were squares of 50 mm x 50 mm x 10 mm in size with an average surface magnetic strength of 1.2 T (Tesla). Seeds were placed 2.83 cm above the surface of the magnets to provide 150 mT strength for different treatment periods. 150 mT MF strength was calculated according to the below formula (B = 0.15 T = 150 mT, FSM (Field Strength of Magnet) = 1.2 T, d (Distance)).

$$B = \frac{FSM}{d^2}$$

The 'Tori' and 'Sarson' seeds were exposed to 150 mT MF strength for different periods (0-control, 24, 48, and 72 hours).

2.2. Soil Preparation, Planting and Plant Development

The soil of the trial field was plowed 30 cm in depth in the fall before winter. In spring, it was plowed again 10-15 cm in depth to prepare soil for planting. Planting was performed in the third week of April with 30 cm row width spaces and 5 cm on-row. Three seeds were put in every hole to guarantee the germination. Two of the plants were eliminated two weeks after germination, and only one plant was left in every hole. During the development period of the seedlings, necessary irrigation and weed control were carried out. After flowering and fertilizing the plants, the tops of the plants were covered with perforated nets to protect the seeds from bird damage. The net gaps are large enough to prevent bird entry and provide sufficient light and airflow for the plants (Figure 1a-b).

2.3. Observations & Harvesting

The seed capsules obtained from the selected plants were collected in paper bags and kept at room temperature in the laboratory until blending and analysis processes. In the threshing process, the seeds in a capsule of each plant were collected in a different paper bag (Figure 1c-d).

Observations were performed in a total of 30 plants (10 plants per replication) for different MF periods. At the end of the study, seed yield per plant (g $plant^{-1}$), seed yield per decare (*kg* da^{-1}), crude oil content (%), and crude oil yield (kg da^{-1}) were determined as agronomic characters.

2.4. Determination of Seed Yield per Plant (g $plant^{-1}$*)*

Seed yield per plant was calculated by averaging the weights of seeds of 10 randomly selected plants for each replication of 150 mT MF strength for different treatment periods.

2.5. Determination of Seed Yield per Decare (kg da^{-1}*)*

Seed yield per decare was calculated by multiplying seed yield per plant with the number of plants per decare for each replication of 150 mT MF strength for different treatment periods.

2.6. Determination of Crude Oil Content (%)

Crude oil content in percentage was calculated by averaging crude oil contents of seeds of 10 randomly selected plants for each replication of 150 mT MF strength for different treatment periods. The seeds were first grinded, and 2 g of grinded pieces were used to determine the crude oil content of the seeds. Crude oil content from seeds of mustard varieties was extracted in the soxhlet apparatus using petroleum ether as a solvent for 6 h according to the AOCS method (AOCS 1993).

2.7. Determination of Crude Oil Yield per Decare (kg da^{-1})

Crude oil yield per decare was calculated by multiplying crude oil content per plant with number of plants per decare for each replication of 150 mT MF strength for different treatment periods.

2.8. Statistical Analysis

The data were subjected to analysis of variance (ANOVA) using IBM SPSS Statistics 22 software. The field experiment was one factorial, completely randomized design, where a comparison was noted among different MF exposure times. The differences between the means in MF exposure time trials were determined using the Duncan test at 0.01. The difference between the varieties was not considered as a factor.

3. Results

The trials established with 150 mT MF treatment of mustard seeds for 24, 48, and 72 hours were completed. Images of the cultivation and post-harvest processes of mustard plants are given in Figure 1. The germination and seedling development of the seeds in the field were uniform. The positive changes in the production process of mustard under the influence of MF are summarized in Figure 2.

Figure 1. The flowering period of mustard plants (a), precautions taken to protect seeds from bird damage after flowering (b), samples collected after harvest (c), preparation mustard seeds for analysis (d).

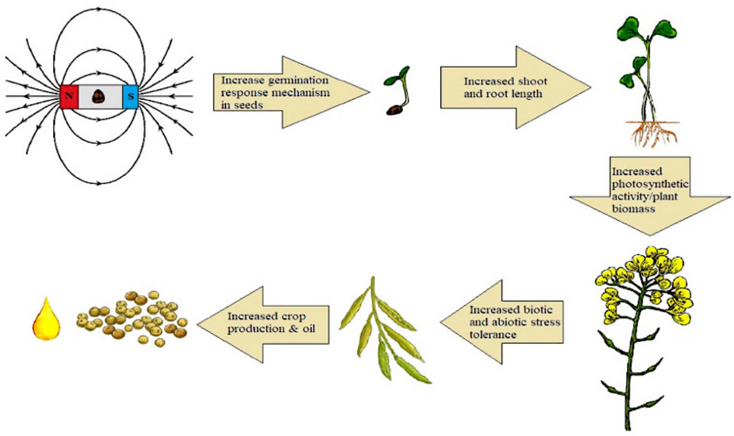

Figure 2. The effects of applying magnetic field intensity on different growth stages of mustard plants are illustrated. The mechanisms activated by seed stimulation increase the plant's tolerance to environmental stresses throughout the growth and development process. In addition to maximum utilization of nutrients and water in the soil, positive changes are observed in biochemical and physiological activities.

Seed yield was recorded as 115.20 kg da^{-1} in control while 165.18 kg da^{-1} in 24-hour-MF treatment as the highest in 'Tori'. In 'Sarson', seed yield increased to 210.39 kg da^{-1} in 48-hour-MF treatment from 136.59 kg da^{-1} in control. The increase in seed yield compared to control was recorded as 43.39% in 'Tori' and 54.03% in 'Sarson'. The mean increase percentage of the two varieties in seed yield was 48.71% (Table 1).

Table 1. The effect of 150 mT magnetic field strength at different treatment periods on seed yield, crude oil content and crude oil yield

Variety	Treatment Period (hour)	Seed Yield (kg da^{-1})	Increase in Seed Yield According to Control (%)	Crude Oil Content (%)	Crude Oil Yield (kg da^{-1})	Increase in Crude Oil Yield According to Control (%)
'Tori'	0-Control	115.20^{b}±2.85	43.39	36.90	42.51^{b}±1.43	38.72
	24	165.18^{a}±1.95		35.70	58.97^{a}±1.81	
	48	106.80^{b}±1.61		34.80	37.17^{c}±0.92	
	72	98.79^{b}±1.74		35.80	35.37^{c}±1.66	
'Sarson'	0-Control	136.59^{c}±2.00	54.03	40.00	54.64^{c}±1.53	44.40
	24	136.20^{c}±2.40		34.80	47.40^{c}±2.00	
	48	210.39^{a}±1.86		37.50	78.90^{a}±1.50	
	72	171.18^{b}±1.68		36.60	62.65^{b}±1.51	

*The difference between the averages shown with different letters for each variety is significant at 0.01 level.
*Each value is the mean of years 2018 and 2019

In 72-hour-MF treatment, seed yield was noted as 98.79 kg da^{-1} in 'Tori' and 171.18 kg da^{-1} in 'Sarson'. In 'Tori', seed yield started to decrease gradually from the highest value obtained in 48- and 72-hour-MF treatments (Figure 3a). The 'Sarson' cultivar showed a greater response than the 'Tori' cultivar to 150 mT MF treatment at different exposure times. Crude oil yield increased to 58.97 kg da^{-1} in 24-hour-MF treatment from 42.51 kg da^{-1} in control in 'Tori'. In 'Sarson', crude oil yield was 54.64 kg da^{-1} in control treatment while it was 78.90 kg da^{-1} in 72-hour-MF. Increase percentage in crude oil yield compared to control was obtained as 38.72% and 44.40% in varieties 'Tori' and 'Sarson', respectively. Overall mean of increase percentage of two varieties in crude oil yield was 41.56% (Table 1, Figure 3b). The highest crude oil contents were recorded as 36.90% and 40.00% in varieties 'Tori' and 'Sarson', respectively. Crude oil contents were determined as 35.70% in 24-hour-MF treatment in 'Tori' and as 37.50% in 48-hour-MF treatment in 'Sarson'. The differences in crude oil contents among different MF treatments in both varieties were found statistically insignificant (Table 1, Figure 3c).

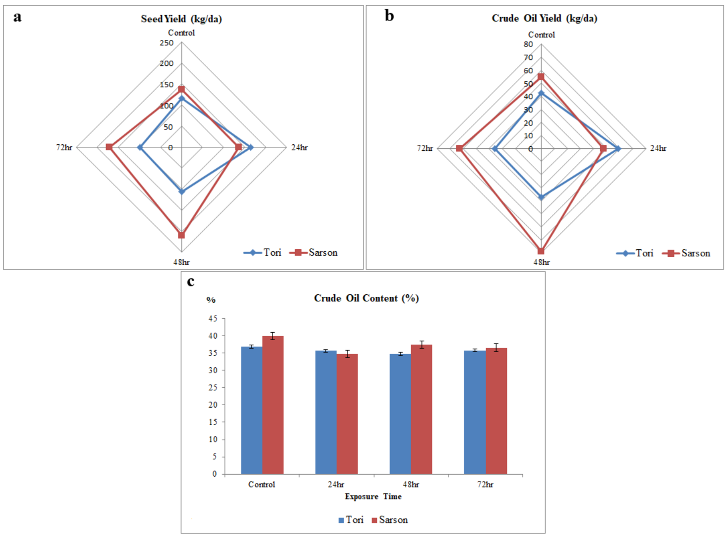

Figure 3. Effects of MF strength for different time periods on seed yield (kg da^{-1}) (a), Effects of MF strength for different time periods on crude oil yield (kg da^{-1}) (b), Effects of MF strength for different time periods on crude oil content rate (%) (c) in varieties 'Tori' and 'Sarson'.

Innovative and eco-friendly approaches such as bio-based technology, renewable energy, and sustainable agriculture are of great importance (Aslan and Eryilmaz 2020; Oğuz et al. 2023). MF treatment strategies are innovative and eco-friendly methods for improving seed germination, vegetative growth, abiotic stress tolerance and yield in most species (El-Gizawy et al. 2016; Beyaz et al. 2020; Okumuş et al. 2023). The MF treatment has the potential to have a positive effect at the cellular level. It could trigger biochemical, molecular, and physiological processes. The impact of the MF treatment could depend on the plant species, type of MF, strength, severity, and duration (Pietruszewski and Martínez 2015; Yildiz et al. 2017).

All living organisms are influenced by the Earth's magnetic field, also known as the geomagnetic field (GMF) (Maffei 2014; Pietruszewski and Martínez 2015). The intensity of the GMF ranges from 25 to 65 μT, and this variation is region-specific (Occhipinti et al. 2014). It has been reported that MF treatments lower than GMF values have negative effects on different physiological and molecular stages of plants (Belyavskaya 2004; Xu et al. 2013). Conversely, it has been stated that the MF treatment at higher rates than the GMF values gives positive results in plant species (Maffei 2014; Aycan et al. 2018; Beyaz et al. 2020). In the current study, under the effect of 150 mT of fixed MF, an increase in seed yield of 54.03% and oil yield of 44.40% was achieved in the 'Sarson' variety compared to the control. In the 'Tori' variety, seed yield increased 43.39% and oil yield increased 38.72%. The 150 mT MF used in the experiment is higher than the GMF as mentioned above. Our results support that high MF values cause an increase in yield parameters. Generally, the yellow seed varieties of *B. campestris* have higher oil content than the brown seed varieties (Hassan 2015). These differences in yield in the 'Tori' and 'Sarson' varieties are mainly due to variety differences. However, the efficiency of the fixed and long-term MF effect was increased compared to the control in both varieties.

MF effect affects a whole or specific structure in the living organism (Pietruszewski and Martínez 2015). The exposure of seeds to higher MF force than GMF increases seed germination and plant growth by increasing water assimilation and photosynthesis (Florez et al. 2007). Conversely, near-zero MF suppresses biomass accumulation in the generative period (Xu et al. 2013). This situation causes the plant to enter the flowering period late, grow late, and become vulnerable to the negative effects of the environment. Seeds exposed to a higher MF effect than GMF germinate faster and more uniformly. Rapid and uniform growth indicates that plants will gain superiority against environmental conditions during vegetative development. In our study, the 'Tori' and 'Sarson' seeds were exposed to a constant (150 mT) MF effect at different exposure times before planting. Although it varies according to the exposure time, a uniform development was observed in each trial plot during the germination, seedling, and flowering period (Figure 1a). According to the harvest results, the oil ratio (%) obtained from both varieties was measured less than the control. However, an increase in oil yield (kg da^{-1}) (38.72% in the 'Tori' variety, 44.40% in the 'Sarson' variety compared to the control) was determined. Seed and oil yield in oilseeds correspond to the total yield alone or together. The oil content (%) of the seeds can affect the obtained oil yield and the high seed yield, which can contribute to the oil yield obtained (Hassan 2015). As Pietruszewski and Martínez (2015) stated, MF effect studies have reported that it varies from μT (microtesla) to mT (miliTesla) and T (Tesla), and the results differ by up to 100 times compared to this. Despite these vast differences in the treated MF values, their effects seem similarly positive. However, in the results of our study; the yield at certain exposure times decreases were observed ('Sarson' variety, 24 and 72 hours). This result supports that the fixed MF effect does not always show a positive effect at different exposure times. In MF effect studies, the most important parameter, in addition to the magnetic field type and intensity, is the exposure time. Physiological, biochemical, and molecular analyses on this subject will contribute significantly to elucidating the MF effect mechanism.

Recently, a few studies have been conducted on the effect of magnetic fields on plant yield parameters. In the experiment conducted on the sunflower plants with the application of the magnetic field, it was determined that there was a significant increase in productivity. It has been observed that exposure of seeds to magnetic fields improves the integrity of the seed coat membrane and reduces cellular leakage and electrical conductivity (Vashisth and Joshi 2017). Similarly, magnetic field treatment for plant seeds has increasing yield parameters for plants growing from seeds, as shown in the current study result. Florez et al.

(2007) emphasized that corn seeds continuously exposed to 250 mT gave the best results in terms of germination and early growth of seedlings. Okumuş et al. (2023) reported increased salt stress tolerance in barley with 150 mT MF seed application. It was also stated that the examined parameters varied according to the exposure time. Vashisth and Joshi (2017) discussed the impact of changing magnetic field (MF) doses on specific seedling parameters in maize plants. The increase in MF strength didn't correspond with physiological development.

Additionally, there was no linear relationship between physiological development and exposure time. In this context, exploring the effects of continuous and consistent MF at different time intervals on various physiological and molecular plant responses is crucial. According to the results of the current study, the best seed yield in the Sarson variety was determined from 48 hours of MF exposure time (Figure 1a). Similarly, the best result regarding crude oil yield in the Sarson variety was determined from 48 hours of exposure time (Figure 1b). On the other hand, the best seed yield and crude oil yield in the Tori variety were determined from 24 hours of exposure time (Figure 1a-b). According to these results, the MF exposure time showed significant differences in yield parameters. Besides, the responses of varieties to MF treatment periods are different.

On the other hand, the effect of MF treatment and exposure times on crude oil content is insignificant (Figure 1c). In light of these results, it was determined that MF treatment and exposure times could have different effects depending on the plant's variety. In future studies, optimization of specific treatment doses and periods specific to species and varieties will increase the potential impact.

4. Conclusions

It was determined that the exposure of mustard seeds to constant MF effect for different exposure times stimulates yield parameters. In a discussion with other research results, it has been demonstrated that MF exposure time is equally essential to MF strength. Time factor is an important parameter to be considered in new optimization studies. Productivity and quality should be the main targets in meeting the needs of the increasing world population and determining the MF effect economically. The results were not carried out at the field condition and have no economic value remaining within the experimental dimension. This type of experiment is limited only to demonstrating the importance of the MF effect. Environmentally friendly and innovative agricultural approaches have become essential for ecological and sustainable life in the current order of the world. The aim of MF studies should be to reveal the potential yields of plant varieties at the highest. Studies on this issue require molecular, physiological, and economic perspectives.

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Research Article

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Bibliometric Analysis of Soil Classification Research in Soil Science from 1980 to 2023

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HIGHLIGHTS

- Publication Focus: A total of 3612 papers out of 4467 documents show that "soil classification" is a major topic in academic publications.
- Growth Rate: Over time, interest in "soil classification" has increased, as evidenced by the 4.74% annual growth rate.
- Author Collaboration: To demonstrate the worldwide reach of the research, each paper had an average of 3.88 authors and a 23.66% international collaboration rate.
- Emerging Research Areas: The application of novel modeling and analysis methods, including artificial neural networks, random forests, support vector machines, gradient boosting, and deep learning methods, has increased recently.

Abstract

Bibliometric analyses shed light on research patterns and the influence of science. Based on 4467 papers from the Web of Science database, this article provides a bibliometric overview of soil science research on soil classification from 1980 to 2023. This study determines four time periods: 1980–1995, 1996–2005, 2006–2015, and 2016–2023. Research between 1980 and 1995 focused on basic subjects such as "adsorption," "classification," and "organic matter." The emphasis switched to environmental issues between 1996 and 2005, with "carbon," "contamination," and "soils" taking center stage. From 2006 to 2015, there was a continued focus on the environment, accompanied by more in-depth research on related subjects. Technological developments became more visible between 2016 and 2023, with particular attention paid to "carbon," "vegetation," "classification," "spatial prediction," "models," and "spectroscopy." Throughout, concepts like "classification," "soils," and "organic matter" were crucial, and after 2005, research on "contamination" and "heavy metals" grew more intense. Technological subjects, particularly "spectroscopy" and "spatial prediction," as well as regional studies, have gained importance. In conclusion, the analysis shows how basic research in soil classification has given way to increasingly intricate, technologically advanced studies that reflect a greater emphasis on the environment and the application of innovative techniques for accurate and thorough soil examinations.

Keywords: Bibliometric analysis; Soil classification; Spatial prediction; Soil ecology; Soil survey and mapping

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1. Introduction

Soil classification plays a critical role in agricultural productivity and environmental management (Talawar and Rhoades 1998; McBratney et al. 2000; McBratney et al. 2003; Minasny et al. 2019; Demir 2024). Over time, soil classification methods and techniques have evolved significantly to meet agricultural productivity and environmental conservation goals (Santos et al. 2000; Mermut et al. 2001; McBratney et al. 2003; Hou et al. 2020; Bhat et al. 2023; Demir and Dursun, 2024). Soil is a complex matrix of physical, chemical, and biological properties that are vital to plant growth and environmental sustainability (Minasny et al. 2014; Usharani et al. 2019; Adewara et al. 2024; Demir 2024). Soil classification is a systematic process used to determine and assess soil properties, providing critical information for optimizing soil use and management in agriculture (McBratney et al. 2000; Ma et al.2019; Demir 2024).

The effectiveness and accuracy of soil classification and analysis techniques directly impact the quality and efficiency of scientific research (Hartemink and Minasny 2014; Brevik et al. 2016; Ma et al.n2019; Srivastava et al. 2021; Wadoux and McBratney 2021; Esetlili et al. 2020; Demir and Başayiğit 2021; Azmin et al.m2024; Demir 2024). Soil classification typically involves the integration of various physical, chemical, and biological characteristics, which determine the precision of soil classification systems (McBratney et al. 2003; Dedeoğlum2020; Karaca et al. 2021; Demir et al. 2022; Dengiz et al. 2023; Demir 2024). In this context, analyzing and interpreting data related to soil properties can enhance classification and management strategies (McBratney et al. 2003; Arrouays et al. 2014; Brevik et al. 2016; Ma et al. 2019; Dede et al. 2022; Kerry et al. 2023).

In recent years, bibliometric analyses have become increasingly popular in scientific research (Souza Oliveria Filho 2020; Mokhnacheva and Tsvetkova 2020; Altay and Kaplan 2023; Jia et al 2024; Tang et al. 2024; Xu et al. 2024; Chen et al. 2024). Bibliometric analyses are powerful tools for evaluating the impact and trends of scientific publications, providing detailed insights such as publication year, citation count, and author collaborations (Altay and Kaplan 2023; Jia et al. 2024). This study conducts a comprehensive bibliometric analysis to identify significant trends and contributions in soil classification research. Soil classification is essential for understanding soil properties, processes, and spatial distribution. By classifying soils, researchers and practitioners can better manage soil resources, promote sustainable agriculture, and mitigate environmental risks (Demir 2024). This study aims to contribute to the advancement of soil science and to support sustainable land-use practices by identifying significant trends and effective research strategies in soil classification.

2. Materials and Methods

For this study, the Web of Science (WoS) database was searched as of May 21, 2024, and 4467 documents on soil classification from 1980 to 2023 were found (see Table 1). The Web of Science database was meticulously searched using a targeted set of keywords, specifically including "soil classification" within the field of soil science, to identify relevant research. Then, using the "convert2pdf" function in R software, data pertinent to soil classification in soil science were extracted from the WoS database in plain text format (R Core Team 2016). Finally, a bibliometric analysis was performed using the R software Shiny program's "bibliometrix" package (Aria and Cuccurullo 2017). The R packages used in this study facilitated an in-depth analysis of publication patterns, keyword trends, and citation networks, enabling a comprehensive interpretation of the data (Table 1). A graphic representation of the patterns in keyword frequency and significance across the four designated periods was provided. This was accomplished by grouping relevant keywords using a clustering technique based on the Walktrap algorithm (Altay and Kaplan 2023).

Table 1. Main ınformation about the data

Timespan	1980-2023	
Sources (Journals, Books, etc.)	198	
Documents (n)	4467	
Document Contents	Keywords Plus (ID)	5754
	Author's Keywords (DE)	8854
Authors	Total Authors	11208
	Authors of Single-authored Documents	410
Authors Collaboration	Single-authored Documents	528
	Co-authors per Document	3.88
	International Co-authorships (%)	23.66
References	131800	

3. Results and Discussion

This analysis of the bibliometric data encompassing 4467 documents from 198 sources between 1980 and 2023 indicates that articles constitute the majority, with 3612 instances. Proceedings Papers and Reviews, 259 and 127, respectively. Other types include Book Chapters, Early Access articles, and different formats. The data indicate a consistent increase in the number of articles published in Soil Science about soil classification traits. The distribution of articles occurs over four significant periods: 16.03% between 1980 and 1995, 16.36% between 1996 and 2005, 29.51% between 2006 and 2015, and 38.10% between 2016 and 2023, with a notable peak in 2018. The temporal patterns and distribution of research output are shown in Figure 1. The results indicate a steady increase in the number of publications on soil classification characteristics within the field of soil science. This trend, as noted in previous studies by Minasny et al. (2010), Mokhnacheva and Tsvetkova (2020), Xu et al. (2022), and Jia et al. (2024), also emphasizes the growing research activities in soil science. Global concerns surrounding climate change, food security, and sustainability have emerged as significant factors driving heightened interest in soil science research.

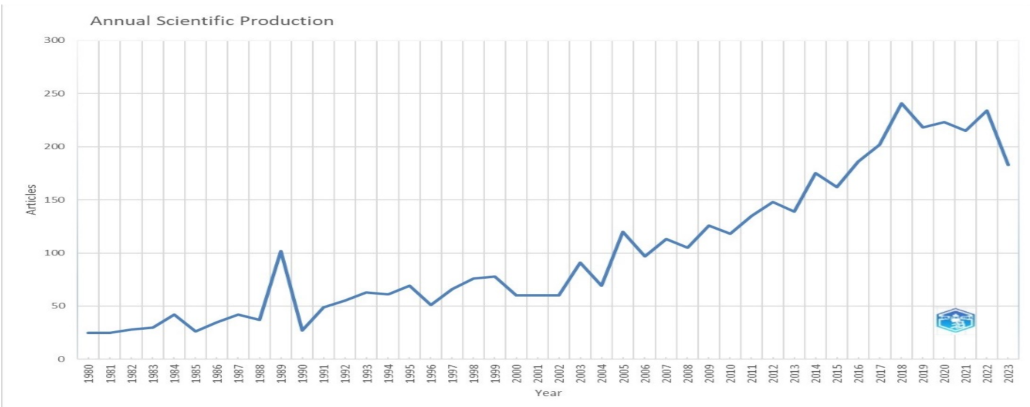

Figure 1. Published articles by years

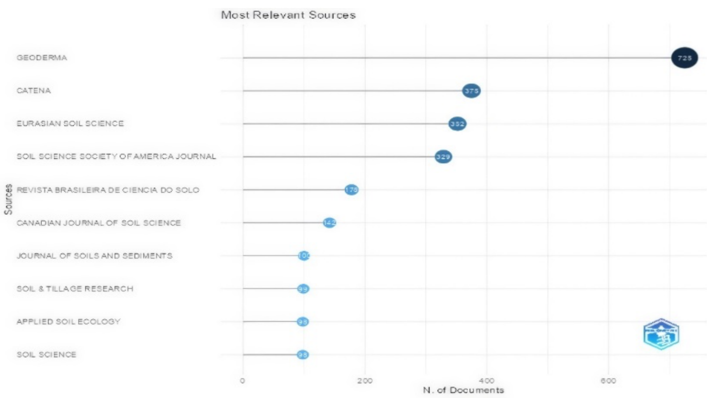

Figure 2. The journal sources of published articles

There are clear trends in the distribution of publications in soil science when journal sources for published papers are examined. The sources of the published papers are shown in Figure 2. With 725 publications, Geoderma has the highest number of publications overall. With 375 papers, Catena was next, followed by Eurasian Soil Science with 352 articles. The Revista Brasileira de Ciencia do Solo (178 articles) and the Soil Science Society of America Journal (329 articles) are two other noteworthy sources. Geoderma is the most prolific of the top journals, indicating its considerable impact on soil science research. Catena and Eurasian soil science have also made significant contributions to the literature on this topic. The distribution of papers in these journals suggests that the research is focused on highly influential publications. These results indicate that focusing on specific journals in studies in literature increases research quality and reliability (Mokhnacheva and Tsvetkova 2020; Jia et al. 2024).

The top 10 most referenced journals on soil classification were assessed out of 43.070 journals. The top ten journals that receive the most citations for soil science and soil classification are shown in Figure 3. Geoderma tops the list with the most citations, closely followed by Catena and the Soil Science Society of America Journal, all of which are heavily featured. Soil Science, Soil Biology and Biochemistry, and the European Journal of Soil Science are a few of the other renowned journals. The distribution of these publications' citations indicates how important and well-known they are in the field of soil classification research. This result aligns with previous studies that have highlighted the influence of these journals in shaping the discourse and knowledge base of soil science (Minasny et al. 2010; Brevik et al. 2016; Mokhnacheva and Tsvetkova 2020; Xu et al. 2022; Jia et al. 2024).

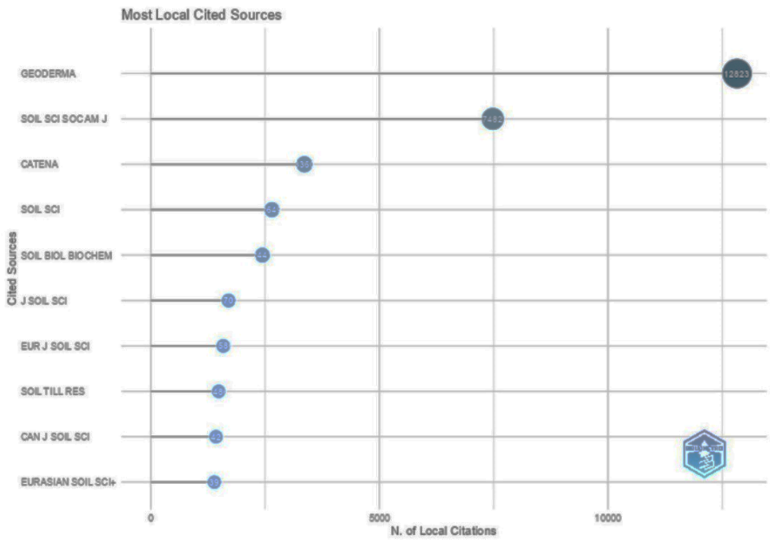

Figure 3. The most locally cited journals

Figure 4 provides information about country-based production between 1980 and 2023. Considering production data, the highest number of articles is seen in the United States (1641) and Brazil (1125), with China (997), Germany (606), and Russia (591) closely behind. Australia (513), Canada (408), France (403), and Italy (339) also contributed significantly to the research output. The fact that country-based production continues to increase over time reveals that studies in this field are a trend. Notably, in recent years, there has been a significant increase in research output in the United States, Brazil, and China, indicating a growing emphasis on this field in these countries. This trend aligns with findings in the literature, suggesting that the growing interest in soil science research is not merely a regional phenomenon but rather a response to pressing global challenges. Because soils are essential for carbon sequestration, crop production, and ecosystem resilience, concerns like climate change, food security, and sustainable development have increased the demand for advanced soil research. As a result, countries with strong research output, such as the USA, Brazil, and China, appear to be prioritizing soil studies as part of broader strategies to address environmental sustainability and resource management on both national and global scales (Minasny et al. 2010; Wang et al. 2015; Hartemink 2019; Jia et al. 2024).

Figure 5 presents information about the most cited studies from around the world. When the 10 most cited studies in this field are evaluated, 9114 citations have been provided to these studies. Among these studies, the first four most cited studies are MCBRATNEY AB, 2003 GEODERMA (2274), ZELLES L, 1999; BIOL FERT SOILS (1596), WESTOBY M, 1998; PLANT SOIL (1412), and BONGERS T, 1998; and APPL SOIL ECOL (869). The significant citation counts of these studies highlight their foundational contributions within soil science and ecology, particularly by advancing methodologies and enhancing our understanding of soil processes and ecosystem interactions. McBratney et al. (2003) in Geoderma introduced a groundbreaking framework for digital soil mapping that integrates diverse environmental data layers, such as terrain attributes and climate factors, into predictive models, transforming soil mapping practices. Zelles (1999) in Biology and Fertility of Soils focused on the use of phospholipid fatty acid (PLFA) analysis to characterize microbial communities, a method that provides critical insights into soil biology and microbial ecology. Westoby et al. (1998) in Plant and Soil proposed the leaf-height-seed (LHS) scheme, which became a widely used model in plant ecology for comparing ecological strategies and understanding plant responses to environmental changes. Bongers (1998) in Applied Soil Ecology introduced a functional diversity framework for nematodes, which serves as an indicator of soil health and quality, highlighting the role of nematode communities in soil ecosystem functioning. These highly cited works reflect the interdisciplinary impact of soil science research that spans fields such as ecology, biology, and environmental science. Their influence stems from their ability to integrate soil science with broader ecological frameworks, making them critical resources for research on sustainable land management, biodiversity, and ecosystem resilience. Their methodologies and results remain valuable for addressing contemporary issues related to soil health, agricultural productivity, and climate resilience, reinforcing the relevance of soil science within global environmental studies.

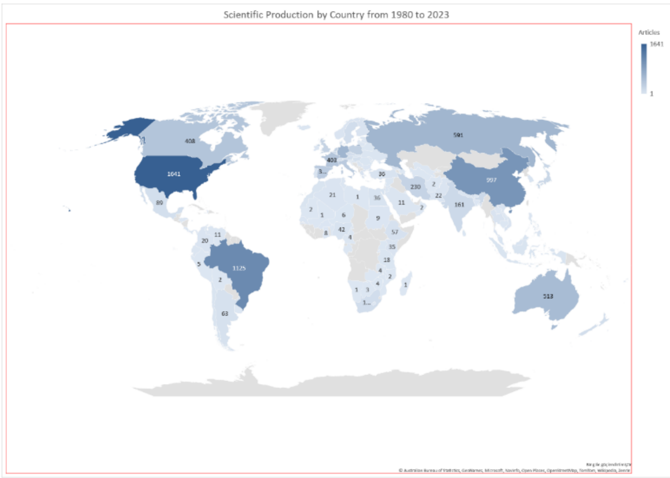

Figure 4. Production by country between 1980 and 2023

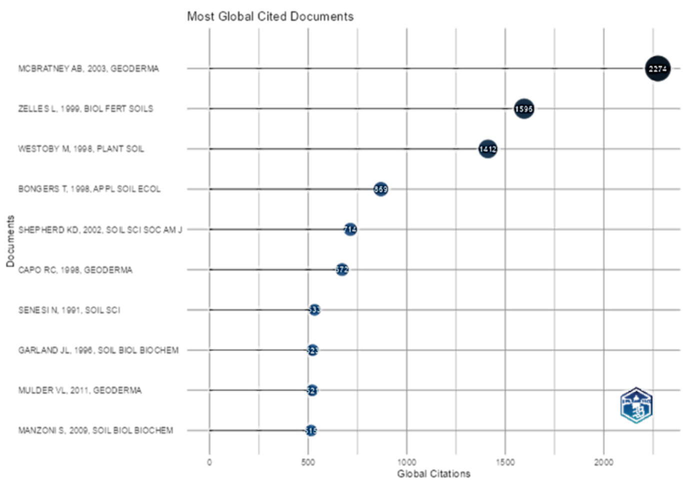

Figure 5. The top publications globally in terms of citation count

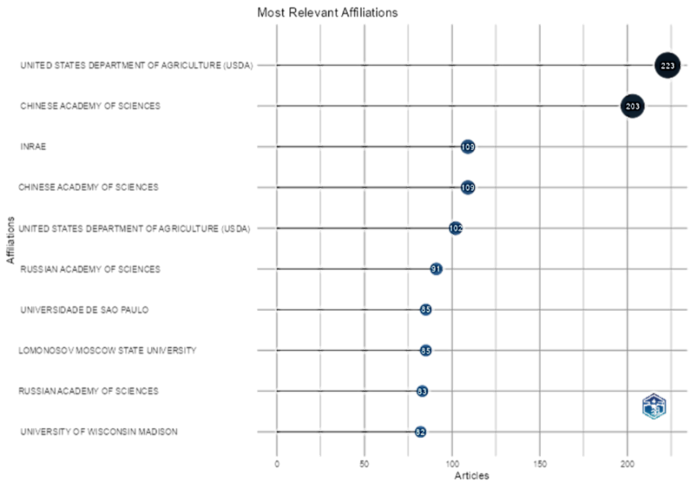

Figure 6. The top scientific affiliations

The top 10 academic institutions with the most published scientific articles are depicted in Figure 6. With 223 articles, the United States Department of Agriculture (USDA) ranks first. The Chinese Academy of Sciences has published 203 articles since the publication of the USDA. The Chinese Academy of Sciences and the French National Research Institute for Agriculture, Food, and Environment (INRAE) contained 109 articles. Other notable organizations included the Russian Academy of Sciences (91 articles), the Universidade de São Paulo and Lomonosov Moscow State University (both 85 articles), the United States Department of Agriculture (102 articles), the Russian Academy of Sciences (83 articles), and the University of Wisconsin-Madison (82 articles). These data highlight that institutions in China and the USA lead in the number of published articles. Similar trends have been reported in other soil science studies, indicating that these countries consistently contribute the highest volume of research in this field (Jia et al. 2024).

Figure 7 illustrates the proximity of the trend topic keywords used in the studies. The trends are represented visually, demonstrating changes in keyword frequency and relevance across the four specified periods. The figure employs a clustering approach (walktrap) to group related keywords, providing a clear view of how research themes have evolved.

Between 1980 and 1995, research in soil science predominantly focused on the fundamental aspects of soil properties and their classification. Key topics during this period included adsorption and classification, which underscored the importance of understanding soil characteristics and developing categorization techniques. The prominence of studies from England suggests a geographical concentration or significant contribution from this region. Research has also concentrated on forest ecosystems and soil growth factors, as evidenced by the frequent use of keywords such as “forest” and “growth.” Hydraulic conductivity and models were also central themes, reflecting growing interest in the physical properties of soil and predictive modeling techniques. The study of optimal interpolation and organic matter was important for understanding soil quality and its components. Notably, the frequent use of keywords like "adsorption" and "mineralogy" indicates a strong focus on soil chemistry and fundamental classification methods.

From 1996 to 2005, there was a notable expansion in research themes. Classification continues to be a major area of interest, emphasizing its continued importance in soil science. The role of organic matter remained central, with substantial research into its impact on soil health. This period also saw the rise of prediction methods, reflecting an increasing interest in forecasting soil properties and conditions. The focus shifted to soil composition and characteristics, with keywords like soils and texture becoming more significant. This era marked a broader interest in environmental management and advanced modeling techniques, as evidenced by the emergence of terms related to environmental impacts and predictive models.

The period between 2006 and 2015 saw a shift in research emphasis toward carbon dynamics and soil classification. The focus on carbon emissions and classification reflects ongoing interests in these areas. However, new critical topics, including contamination and heavy metals, have emerged, highlighting growing concerns about soil pollution and environmental contamination. Research has continued to emphasize soils, with an expansion into various aspects of soil science, including physical and chemical properties. The increased focus on keywords like "contamination" and "spatial prediction" during this period indicates heightened concern with soil quality, pollution, and advancements in analytical techniques.

In the most recent period, from 2016 to 2023, research trends have shifted toward the refinement of soil classification systems and a deeper understanding of soil properties. Classification and soils remain prominent areas of study. The integration of plant-soil interactions has become increasingly significant, as evidenced by the rise in research on vegetation. Additionally, spatial prediction has gained importance, reflecting advancements in soil-wettability prediction techniques across various spatial scales. The continued prevalence of terms related to "heavy metals" and "vegetation" suggests a sustained focus on pollution impacts and the role of vegetation in soil management. This ongoing research reflects an evolving understanding of soil science, addressing both historical concerns and emerging issues in the field. Such studies build on a foundation of previous research, as highlighted in recent literature, emphasizing the critical role of soil health in global ecological and agricultural sustainability (Minasny et al. 2010; Lehman et al. 2020; Brichi et al. 2023; Jia et al. 2024; Feng et al. 2024).

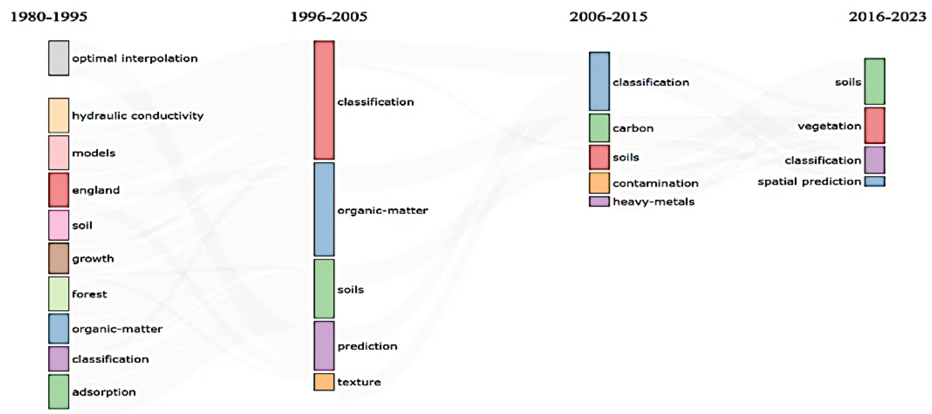

Figure 7. Interrelation of trending keywords by period

The closeness of the trend topic keywords used in the studies is illustrated in Figure 8. An analysis of keywords in the field of soil science revealed three distinct groups. The analysis of keyword metrics in soil science research (Figure 8) reveals distinct clusters with varying degrees of centrality and influence (Jia et al., 2024). An analysis of keywords in the field of soil science revealed three distinct groups. In the first group, this cluster is notable for its high betweenness centrality and significant PageRank scores, which highlights its central role in the research network (Xu et al. 2022). Key nodes in this cluster include "classification," "organic-carbon," "model," and "vegetation." Among these, "classification" stands out with its highest betweenness centrality of 312.01 and a PageRank of 0.139, underscoring its critical role in connecting various research topics (Mcbartney et al. 2003; Xu et al. 2022). Other important nodes such as "organic-carbon" and "model" also exhibit notable betweenness centrality values (8.68 and 5.64, respectively) and moderate PageRank scores, which emphasize their relevance to the research field. Keywords like "erosion" and "spatial prediction" have lower metrics, which indicates their more specialized or emerging roles (Mao et al. 2018; Bezak et al. 2021). In the second group, this cluster comprises keywords such as "organic-matter," "carbon," and "management," which show substantial PageRank and betweenness centrality values. "Organic-matter" and "carbon" are particularly significant, with high betweenness centrality values (20.95 and 14.95) and PageRank scores (0.040 each), reflecting their central roles in discussions about soil quality and carbon dynamics (Brichi et al. 2023; Feng et al. 2024). Keywords like "nitrogen" and "water" also possess noteworthy scores, emphasizing their importance in soil management and environmental studies (Zhang et al. 2020). In the third group, this cluster includes keywords like "soils," "genesis," and "evolution." Although these keywords have lower betweenness centrality than the first and second keywords, they still contribute to the broader understanding of soil science. "Soils" has a moderate betweenness centrality of 2.90 and a PageRank of 0.016, indicating its foundational role in the field. Keywords such as "genesis" and "evolution" have lower metrics but continue to be relevant for specific research areas (Xu et al. 2022).

In conclusion, the analysis highlights the hierarchical structure of research keywords, with terms like "classification" and "organic-matter" being highly central and influential within soil science research. Figure 8's clustering and ranking of keywords offer important information about the field's focal regions and changing trends.

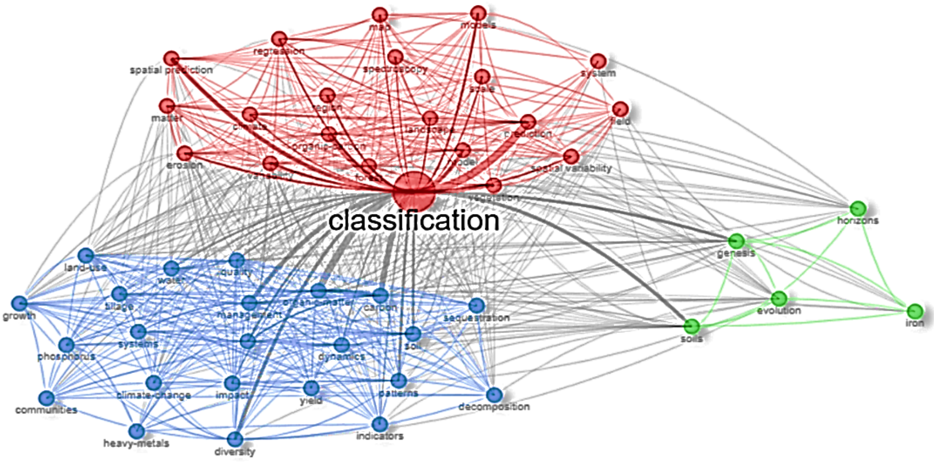

Figure 8. Interrelations among trending keywords

4. Conclusions

This bibliometric analysis of 4467 papers on soil classification from 1980 to 2023, sourced from the Web of Science database, revealed significant trends and shifts in research focus. Early research (1980–1995) centered on fundamental topics like 'adsorption' and 'classification,' evolving to environmental concerns such as carbon and contamination between 1996 and 2005. From 2006 to 2015, the emphasis shifted toward soil pollution and advanced analytical methods, while the most recent period (2016–2023) highlighted advancements in technological approaches, including "spectroscopy" and "spatial prediction." Key institutions, notably from the USA and China, lead research output, and influential journals such as Geoderma and Catena dominate the field. Additionally, Türkiye's research has moderate betweenness centrality (0.0744) and PageRank (0.0066), indicating its significant role in regional collaborations and knowledge sharing. This underscores Turkey's significant contribution to enhancing regional research and information dissemination. The data shows a growing focus on incorporating technological innovations and addressing environmental challenges in soil science research. In the future, research is expected to build on this trend, with a greater emphasis on integrating emerging technologies and interdisciplinary methods. This approach will likely enhance efforts to tackle complex environmental issues and improve soil management practices.

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Conflicts of Interest: The authors declare no competing interests.

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Research Article

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Investigation of the Structural Characteristics of Seed Surfaces of Some Soybean Genotypes by Using Scanning Electron Microscopy (SEM)

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HIGHLIGHTS

- One of the most important legume plants in the Fabaceae family, soybeans are essential for both human and animal nutrition.
- The characterization of different genotypes and varieties of soybeans is too important for plant breeding and SEM seed surface examinations are a low-cost and effective technique for characterizing of them.

Abstract

Soybean (*Glycine max*) is an annual plant in the Fabaceae family, native to East Asia. The plant is grown for its edible beans. Soybean plays a crucial role in East Asian cuisine and the animal feed industry as it is one of the plants with the highest protein yield per cultivated area and is rich in nutritional value. Since soybean cultivars are morphologically similar, molecular and genetic markers are mostly used to determine different varieties and lineages. It is extremely important to prefer more effective and practical approaches for faster and cheaper characterization of agricultural products. In this respect, SEM analyses, which allow seed surface characterization of not only soya varieties but also all grains are foreseen to be of critical importance as a candidate method and approach. SEM technique provides high-resolution images of the surfaces and allows detailed examination of the microstructure of the materials. This study used Scanning Electron Microscopy (SEM) to determine seed surface characteristics such as surface roughness, reticulation, tubercles, and raised and grooved surface decorations in 12 soybean cultivars. As a result of the study, soybean genotypes were divided into 3 types according to their micro-morphological characteristics and their similarities and differences were revealed. In conclusion, it is thought that such a classification based on surface traits could be a potential method to help identify and compare seeds, especially in the identification of hybrid plants. In addition, valuable data can be obtained with this method during the use of wild forms of cultivated plants in breeding programs.

Keywords: *Glycine max*, seed surface ornamentation, Türkiye.

1. Introduction

Soybean, an important legume plant from the Fabaceae family, is used in both human and animal nutrition (Kuromori et al. 2022). First identified in China and referred to as the 'miracle plant,' soybean was cultivated approximately 5000 years ago and later spread to the United States (USA) and Europe (Zhao and Gai 2004).

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The cultivated form of soybean, *Glycine max*, was first domesticated from the wild species *Glycine soja* in China, and from there it spread to Japan, South Korea, and North Korea (Boerma and Specht 2004). Although soybean is one of the most important cultivated crops in the worldwide today, it was not well known outside of the Far East until about 100 years ago. In our country, soybean was first cultivated as a primary crop in the Black Sea region during World War I, and as a secondary crop in the Mediterranean and Aegean regions between 1968 and 1970 (İşler and Coşkan 2009). According to the 2021 data from the Food and Agriculture Organization (FAO) of the United Nations, the global cultivation area of soybean is 126.95 million hectares, with a production quantity of 353.46 million tons, and an average yield value of 2.78 tons per hectare. The leading countries in terms of cultivation area are Brazil (37.1 million hectares), the USA (33.3 million hectares), Argentina (16.7 million hectares), India (12.1 million hectares), China (9.8 million hectares), Paraguay (3.6 million hectares), and Canada (2 million hectares) (FAO 2021). In Türkiye, soybean production amounted to 182.000 tons in an area of 43.891 hectares in 2021, with an average yield of 4.15 tons per hectare (TURKSTAT 2021). Adana, Mersin, Samsun, Osmaniye, and Kahramanmaraş provinces constitute 97% of the soybean cultivation area in Türkiye. In soybean production, Adana province ranks first with 62.8%, followed by Mersin with 16.8%, Kahramanmaraş with 7.1%, Osmaniye with 5.8%, and Samsun with 3.4%. Soybean ranks first among oilseed crops imported into our country. Türkiye is largely dependent on imports for its soybean needs, and in 2020, 3.040.452 tons of soybean were imported, with an expenditure of 1.2 billion dollars. Our self-sufficiency rate in domestically produced soybean is 4.9% (FAO 2021).

Soybean seeds contain on average 18-24 % oil, 36-40 % protein, 26 % carbohydrates, and 8 % mineral matter, making it an important food raw material for essential nutrients such as protein, fat, and milk (Arıoğlu 2007). Soybean ranks first among oil crops in terms of cultivation area and production quantity worldwide. Although numerous studies have been conducted on the nutritional value and content of soybean due to its consumption as food (Omoni and Aluko, 2005; Szostak et al., 2020; Dukariya et al., 2020; Carrera et al., 2021; Kumar et al.,2023), genotype characterization and determination of seed surface properties have not received sufficient attention. The importance of seed morphology in determining evolutionary patterns and species identification as well as phylogenetic relationships is supported by many features provided by seed micromorphology (Johnson et al. 2004; Attar et al. 2007). Ultrastructural features of the seed, especially the seed surface and cell shape, are considered important discriminators at intra- and interspecific levels (Kubitzki et al. 2013). In plant breeding, morphological markers which are based on visually accessible characteristics including flower colour, seed form, growth behaviours, and pigmentation are used to identify genetic variation (Govindaraj et al., 2015). In crop production, seed morphology (macro and micro) can be particularly important in breeding and identification of species/hybrid lines. In this context, Scanning Electron Microscopy (SEM) appears to be a powerful tool for obtaining high-resolution images of objects. With this technique, three-dimensional images are obtained by correlating surface features with depth. Seed characters revealed by scanning electron microscopy or SEM are widely used to address various issues primarily related to external characteristics, systematics and evolutionary relationships among species (Segarra and Mateu 2001). To our knowledge, there is no SEM study showing the surface ornamentation of soybean seeds, but there are studies on species belonging to the same family, and these studies clearly show how important seed surface morphology is in distinguishing genotypes (Zoric et al. 2010; Güneş 2013; Erkul et al. 2015; Rashid et al. 2018; Waheed et al. 2021; Kashyap et al. 2021; Rashid et al. 2021).

This study aims to visualize seed surface ornamentation in 12 soybean cultivars and varieties using the SEM technique. It will thus reveal similarities or differences between them using various features such as surface roughness and reticulation and determine the importance of these features in genotype selection.

2.Materials and Methods

Soybean seeds were provided by Prof. Dr. S. Ahmet BAĞCI. A total of 12 cultivars were examined for macro/micro-morphological variations. After cleaning the seeds, macromorphological measurements were made under a binocular microscope. The seeds were evaluated in terms of macromorphological characteristics (testa colour, hilum colour and shape), and the obtained data and measurements are given in Table 1. At least ten soybean seeds were used for each cultivar and the best one was selected. Then seeds were dehydrated, carbon dioxide-critical-point dried, and mounted on stubs with double-sided adhesive tape for SEM inspection. Using a JEOL JSM-6060 model SEM in low vacuum mode, the seeds were coated with gold at a thickness of around 20 nm to observe their surface features (Candan et al. 2009; 2016). SEM images were captured at 86× magnification for the overall view of the seeds, 10K× for the overall view of the seed surfaces, and 30K× for up-close views of the microstructural characteristics of the seeds for all genotypes. Structural nomenclature for seed surfaces was performed following the International Seed Morphology Association (ISMA) seed surface feature comparison chart (2022).

3.Results and Discussion

In this study, the seeds of soybean cultivars were examined macro- and micro morphologically. The seed macro morphological characteristics and seed surface patterns are given in Table 1, Table 2, and Figure 1. In the macromorphological measurements made in this study, seed length/width ratios (L/W ratio) were found to be very close to each other. The smallest seeds belonged to the Mersoy genotype (L/W ratio: 1.07) and the largest seeds belonged to Gapsoy, Lider and Mona genotypes (L/W ratio: 1.17). All seeds are yellow in colour, spherical flat type and medium-sized. The importance of seed morphology in determining phylogenetic relationships as well as evolutionary patterns and species identification is supported by a number of features provided by seed micromorphology (Johnson et al. 2004; Attar et al. 2007). It has been discovered that seed morphology, as well as the composition and morphology of the seed coat, are valuable taxonomic traits (Algan and Büyükkartal 2000; Segarra and Mateu 2001; Bobrov et al. 2004, Hassan et al. 2005). Many species or genera can be identified with great assistance from seed features (Juan et al. 2000; Moro et al. 2001; Segarra and Mateu 2001). Morphological characteristics, such as ornamentation on the testa and seed shape, are frequently employed to identify between species and variations (Aniszewski et al. 2001). Compared to other organs, fruits and seeds often exhibit lower levels of phenotypic plasticity (Bonilla-Barbosa et al. 2000). Seed characteristics are often unaffected by environmental conditions and commonly reflect genetic differences. Angiosperm taxa exhibit significant variation in seed morphology, with rather constant seed structure within small taxonomic groupings (Esau 1977; Hassan et al. 2005).

Table 1. Detailed information about soybean seeds macromorphological characteristics

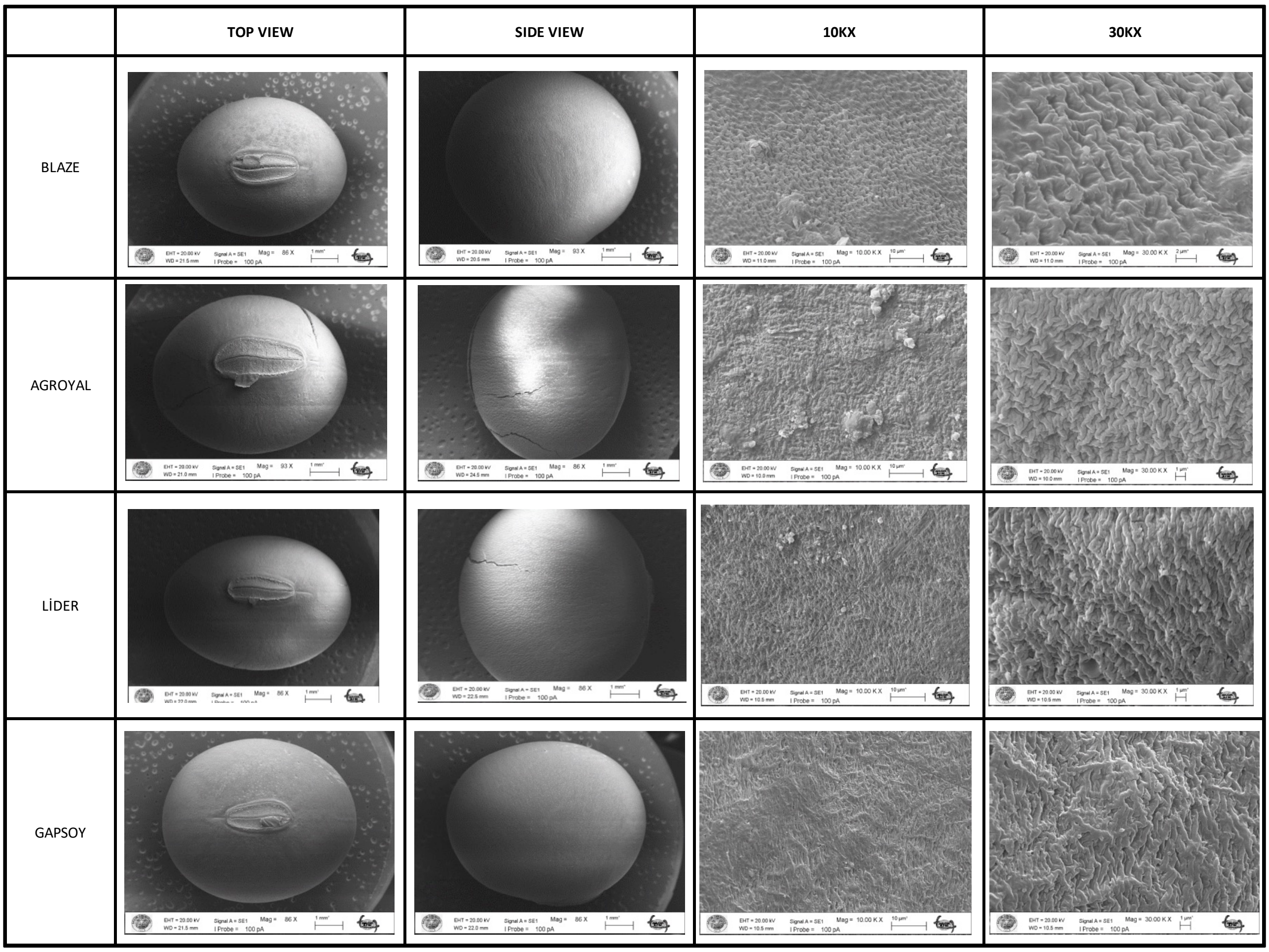
Soybean Cultivar	L (mm)	W (mm)	L/W ratio	Seed coat (testa) color	Hilum color	Seed shape
BLAZE	6.8	6.3	1.08	Yellow	Black	Spherical flattened
AGROYAL	6.4	5.5	1.16	Yellow	Black	Spherical flattened
LİDER	6.9	5.9	1.17	Yellow	Black	Spherical flattened
GAPSOY	6.9	5.9	1.17	Yellow	Dark Brown	Spherical flattened
ATLAS 3616	6.5	5.7	1.14	Yellow	Imperfect black	Spherical flattened
MAY 6301	6.9	6	1.15	Yellow	Dark Brown	Spherical flattened
MONA	6.9	5.9	1.17	Yellow	Black	Spherical flattened
ALPEREN	7.3	6.3	1.16	Yellow	Dark Brown	Spherical flattened
AVON	6.6	5.8	1.14	Yellow	Dark Brown	Spherical flattened
MERSOY	6.5	6.1	1.07	Yellow	Dark Brown	Spherical flattened
UMUT	6.6	6.1	1.08	Yellow	Dark Brown	Spherical flattened
PINAR	6.3	5.6	1.13	Yellow	Black	Spherical flattened

SEM technique was used to reveal the micro morphological similarities and differences between seed surfaces. Detailed information about the structure of the seed surface of these genotypes is provided in Table 2. In this study, seed similarity levels were evaluated as Type A, Type B and Type C based on surface characteristics. Firstly, when evaluated according to seed surface characteristics, Blaze seed belongs to Type A and was identified as having the highest level of distinctiveness with unique surface characteristics. It is distinguished from other seeds by its stippled/pitted surface roughness, wavy ridged reticulation, warty tubercles and decorative veins. Agroyal, Lider, Gapsoy, Atlas, May 6301, Mona and Alperen seeds were grouped in Type B since their surface characteristics were very similar. Looking at the seed surfaces, the stippled surface roughness, wavy ridged reticulation, warty tubercles and vein decoration are consistent among these seeds. The other seeds Avon, Mersoy, Umut, and Pınar have unique surface characteristics different from Type A and B seeds and are classified as Type C. Scurfy surface roughness, ridged reticulation, irregular tubercles and irregular dorsal ornamentation (ridges) are characteristic features of this group (Figure 1).

As a result, it was determined that morphological characteristics such as seed size, general shape and seed colour were not distinguishing characteristics in the studied varieties, but micromorphological characteristics such as seed surface ornamentation could be distinguishing characteristics for soybean genotypes.

Table 2. Seed surface characteristics of the studied soybean cultivars.

Cultivar name	Type	Surface Roughness	Reticulation	Tubercles	Raised and Grooved Surface Decoration
BLAZE	A	Stippled/Pitted	Wavy ridged	Warty	Veins
AGROYAL	B	Stippled	Wavy ridged	Warty	Veins
LİDER	B	Stippled	Wavy ridged	Warty	Veins
GAPSOY	B	Stippled	Wavy ridged	Warty	Veins
ATLAS 3616	B	Stippled	Wavy ridged	Warty	Veins
MAY 6301	B	Stippled	Wavy ridged	Warty	Veins
MONA	B	Stippled	Wavy ridged	Warty	Veins
ALPEREN	B	Stippled	Wavy ridged	Warty	Veins
AVON	C	Scurfy	Ridged	Irregular	Irregular ridges
MERSOY	C	Scurfy	Ridged	Irregular	Irregular ridges
UMUT	C	Scurfy	Ridged	Irregular	Irregular ridges
PINAR	C	Scurfy	Ridged	Irregular	Irregular ridges



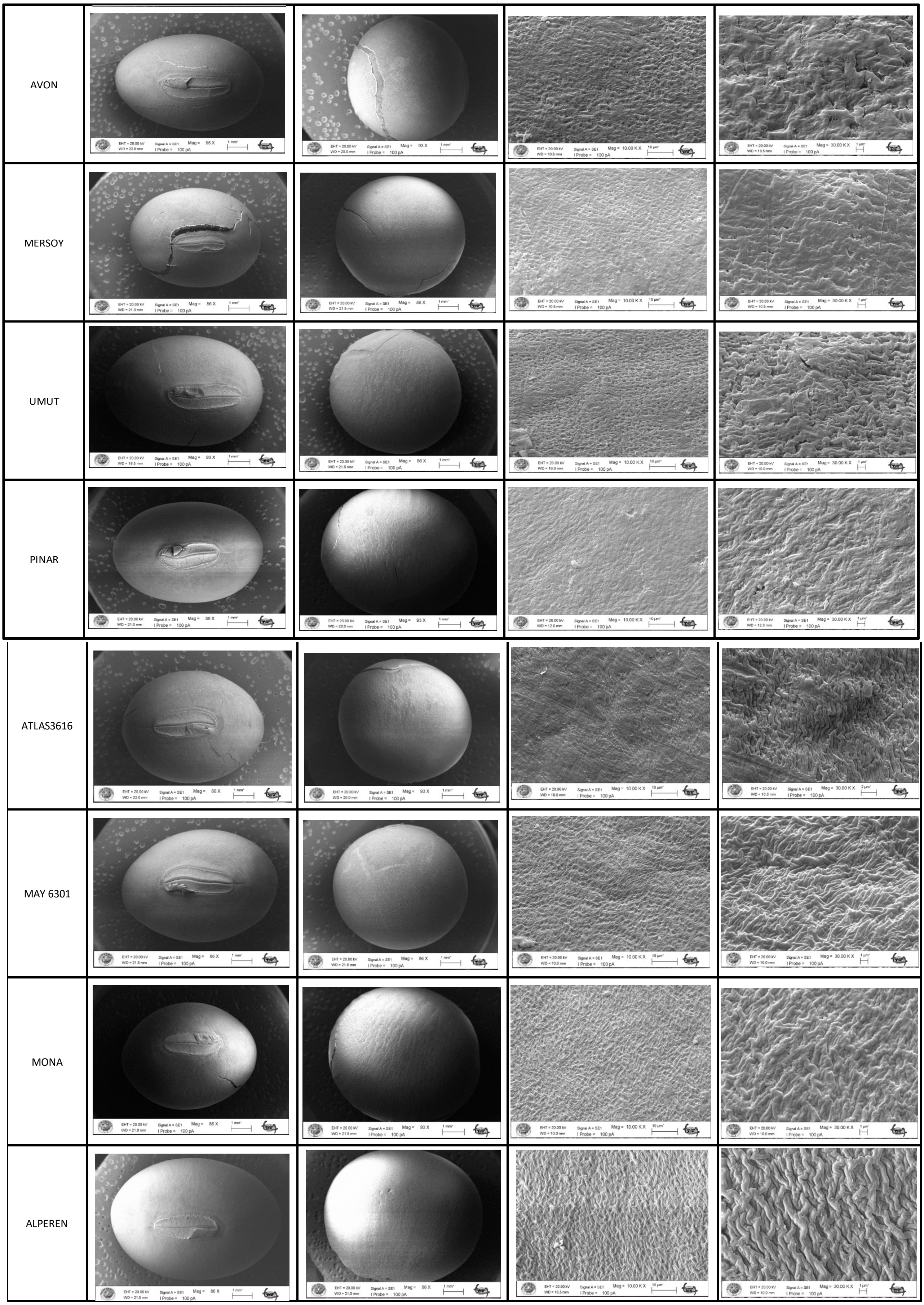


Figure 1. Scanning electron microscope photographs (SEM) of the investigated soybean seeds.

According to our literature review, there is only one study related to SEM analysis of soybean seeds, but in the study, instead of separating the cultivars, two soybean cultivars were evaluated with SEM technique in terms of water permeability and it was reported that the water permeability of the seed decreased due to small cuticle cracks on the seed surface (Chavan et al. 2021). However, there are similar studies on the determination of seed surface properties in species belonging to the *Fabaceae* (*Leguminosae*) family. Zohary and Heller (1984) carried out initial investigations on the seed surfaces of 24 *Trifolium* species. They identified five types of seed coat patterns and reported that the seed surface was smooth, rough, tuberculated, wrinkled or pitted. Algan and Büyükkartal (2000) described the ultrastructure of the seed coat of *Trifolium pratense* and reported that the seed coat was composed of elongated macroclerids. Slattery et al. (1982) analyzed the color of the seed coat of *Trifolium subterraneum* and its relationship with phenolic content and permeability and reported that seeds were oval and spherical in shape and the seed coat was smooth, striated and wrinkled. The study by Zoric et al. (2010) aimed to describe and compare the external seed morphological characteristics of 38 *Trifolium* species and to evaluate their possible use for taxonomic evaluations. As a result of the study, it was emphasized that more studies should be carried out on more characters to facilitate identification within these groups due to small differences in seed macro and micro morphological characteristics. Rashid et al. (2018) examined the micro-morphological and ultrastructural characteristics of seeds for 12 species within the Vicieae tribe in Pakistan to study taxonomic traits that can be useful in differentiating between species at the generic or infra-generic level. Their findings indicated that seed micromorphology was a highly helpful criterion for separating different species within the Vicieae tribe. To assess the taxonomical significance of macro/micro-morphological seed characteristics, Rashid et al. (2021) used SEM to examine the seed morphology of 12 species from 5 genera of tribes Astragaleae and Trifolieae (*Leguminosae*; *Papilionoideae*). They stated that an SEM investigation had identified important and remarkable seed morphological characteristics in several *Astragaleae* and *Trifolieae* tribe members. The seeds' size, shape and ornamentation are noted as important characteristics for identifying the species under study. Their results also demonstrated how latent morphological affinities between species can be found through SEM in seed morphology. Waheed et al. (2021) employed the scanning electron microscopy technique to compare the micromorphological characters of seeds in the identification of 12 Fabaceae species from Sanghar district of Pakistan and they reported that the SEM studies revealed significant characters of seed surfaces that contain enough information about seed to be recognized as determination of the species and genus levels in the subfamilies *Papilionoideae*, *Caesalpinioideae* and *Mimosoideae*.

4. Conclusions

In conclusion, SEM surface analysis is an inexpensive and effective method for the characterization of soybean genotypes. At the same time, the SEM method can be considered as a potential method for following and determining the characteristics of hybrid plants. In addition, this method has the potential to provide valuable data during the use of wild forms of cultivated plants in breeding programs. The data obtained will provide valuable information for agricultural research and practical applications and will lead to a better understanding of genetic diversity in soybeans.

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Research Article

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Farmers' Participation in Agricultural Fairs and Determination of Their Satisfaction Level; Konya Agricultural Fair Example

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HIGHLIGHTS

- Agricultural fairs are organizations that provide important information exchange and innovation opportunities for farmers.
- Agricultural fairs are important organizations for farmers to learn about new technologies and products.
- Farmers' satisfaction with agricultural fairs varies depending on the quality of the organization, the applicability of the information provided, and commercial opportunities.
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Abstract

The objective of the study was to determine the level of satisfaction among farmers who participated in the Konya Agricultural Fair with regard to their experience of agricultural fairs. The sample size was calculated according to simple random probability sampling based on finite population ratios. A survey was conducted with 96 farmers participating in the Konya agricultural fair. The age, education level, and social security status of the farmers were given with simple percentage calculations. The reasons for farmers' participation in agricultural fairs and their satisfaction levels with agricultural fairs were measured with a 5-point Likert scale. The research results showed that the farmers participating in the agricultural fair were between 30 and 49 and were high school and secondary school graduates. The vast majority of them had social security statuses such as Bağkur. It was determined that the participants participating in agricultural fairs generally had an intermediate level of education and that the farmers were satisfied with the agricultural fair. Rapid developments have also emerged in industry and technology with the globalization of the world. Fairs have a very important share in the introduction of these technologies. In addition, fairs have become the biggest dynamics of the need for socialization limited by development. Therefore, efforts should be made to increase the number of participants in agricultural fairs, and the participation of farmers in the fairs should be increased. In particular, farmers participating in agricultural fairs should be provided with access to financial resources to purchase the technologies they see at the fair.

Keywords: Agricultural Fairs; Farmer; Konya; Satisfaction Level

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1. Introduction

Agriculture plays an important role in economic and social development in most underdeveloped and developing countries (Mokotjo and Kalusopa 2010; Zhang et al. 2016). Agriculture is an important factor in improving the living conditions of rural people especially farmers (Manda 2002). Adequate quality of information is a necessary condition for the improvement of all areas of agriculture (Mao 2012). The provision of agricultural information plays a decisive role in the general development of agriculture as well as in the improvement of farmers' livelihoods (Li 2009; Milovanović 2014). Agricultural information is dynamic due to the increasing awareness of farmers about their needs. The emerging information requirement is demand-driven, unlike the public information system provided during the green revolution. The challenge is to increase farmers' access to information and its importance in agricultural development (Sharma 2002). Farmers use a combination of formal and informal information sources to secure information (Mittal and Mehar 2013). Agricultural fairs are among the sources of agricultural information.

Fairs have been an integral part of the cultural life of society since ancient times. Even in today's information explosion era, fairs are vital for the rural masses as a source of new information, entertainment, and a platform for the exchange of goods (Netrapal et al. 2015). Agricultural fairs constitute extremely important events within the agricultural sector by facilitating the exchange of products and services while also contributing to society through conferences, training sessions, and technology exhibitions (Gutierrez et al. 2024). Agricultural fairs have historically played a critical role in rural economic development by providing a meeting place for the trade of agricultural products, supplying farm supplies, learning new and innovative agricultural techniques, and providing a variety of entertainment services (Kniffen 1949; Lin 1992; Schwartz, 1994; Kelly 1997; Brunt 2003; Longley et al. 2005; Mitchell 2007; Chang 2009; Laflin et al. 2010; Detre et al. 2011; Padilla et al., 2019). Agricultural fairs are fascinating and important planned events (Larsen 2007). The role of fairs as marketplaces for trading farm products, procuring farm supplies, and acquiring innovative agricultural knowledge has significantly diminished (Borish 1997; Mitchell 2007; Chang 2009; Roberts 2015). Agricultural fairs uniquely provide opportunities for social engagement, entertainment, youth development, and exposure to various agricultural product sectors. Fairs also serve educational purposes with exhibits showcasing new technologies and/or stakeholder groups that provide access to non-farm visitors (Mahoney et al. 2020). The role of agricultural trade fairs is to disseminate information on agricultural techniques and technologies used in large-scale production, including marketing, as well as the organization of pavilions for marketing products from family farming (Gazolla and Schneider 2015). The study aims to determine the participation of farmers in agricultural fairs and their satisfaction levels. Since satisfaction is an unobservable abstract concept, it cannot be measured directly (Acharya and Lillywhite, 2021). Several empirical approaches to measuring satisfaction have been proposed in the literature (Iso-Ahola 1980; Iso-Ahola 1982; Iso-Ahola 1989; Nicholson and Pearce 2001; Yoon 2005; Hsu et al. 2009; Lee and Hsu, 2013). In the study, farmers' participation in agricultural fairs and their satisfaction levels were determined with a 5-point Likert scale, which is an empirical approach, as in other studies. Additionally, there is no study in the region on the participation of farmers in agricultural fairs and the determination of their satisfaction levels.

2. Materials and Methods

The main material of the study consists of farmers who came to the Konya province Agricultural Fair. The number of surveys used in the study was calculated according to simple random probability sampling based on finite population proportions (Newbold 1995), which is also used in many studies (Çobanoğlu et al. 2003; Armağan and Akbay 2007; Büyükbay et al. 2009) to reach the maximum sample size in limited populations. According to the data received from the fair authorities, the number of visitors who attended the Konya Agricultural Fair in 2023 was taken as 241,500 people.

$$n = \frac{N\ p\,(1-p)}{(N-1)\,\sigma^2_{px} + p(1-p)}$$

In the formula;

n: Sample volume,

N: Total number of people in the sampling frame,

p: Probability of being a farmer (based on 50% assumption),

σ^2_{px} : variance of the ratio (with a 95% confidence interval and a 10% margin of error to reach the maximum sample volume).

Since it was not known at the beginning how many of the participants who participated in the fair constituting the main mass were farmers, p=0.5 was taken to maximize the sample size. The sample size was taken as p=q=0.5 and calculated as 96 to reach a 95% confidence interval, 10% margin of error, and maximum sample size in the formula. A survey was conducted with 96 farmers who participated in the Konya agricultural fair. The age, education level, and social security status of the farmers were given with simple percentage calculations. The reasons for the farmers' participation in agricultural fairs and their satisfaction levels with agricultural fairs were measured with a 5-point Likert scale. The Likert scale was developed by Rensis Likert (1932) to measure the attitudes, tendencies, and opinions of individuals and groups. Likert-type questions include options that examine the attitudes and behaviors of individuals or groups on the subject under investigation and indicate the level of participation. The Likert scale was developed by Rensis Likert in 1932 and individuals are generally asked to rate the statements on five categories in the attitude scale (Likert 1932).

3. Results

The fair paves the way for participants to meet and collaborate with industry representatives from all over the world. (Bardak and Özdaşlı 2019). These centers on trade routes such as the Royal Road and Silk Road, which have an important position regionally and internationally, have served as fairs throughout history. (TBMM 2013). Fairs can be planned as large or small-scale organizations according to their purpose; they are also used to promote similar products or a wide range of products. (Keleş 2018). Konya Agricultural Fair has significant potential for the Konya region. The differences in people's interests are related to many factors such as people's personal characteristics, age, gender, beliefs and values, upbringing, family structures, living standards, education and income levels, and habits. (Torun et al. 2012). The age status of the participants attending the fair is given in Graph 1.

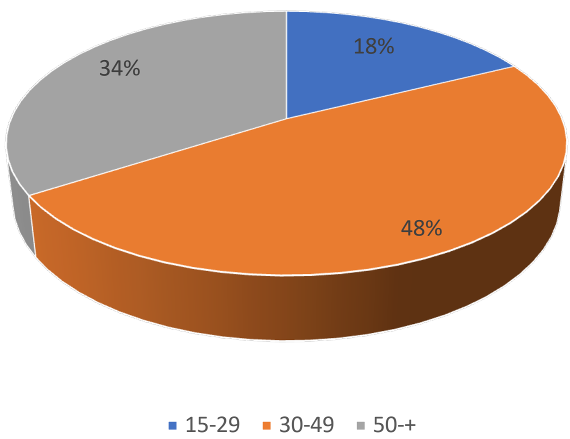

Figure 1. Age of the participants in the fair (%)

According to the graph, 48% of the participants are between the ages of 30-49, 34% are between the ages of 50 and above, and 18% are between the ages of 15-29. The educational background of the participants attending the fair is given in Graph 2. In a similar study, approximately 77% of the fair participants (producers) are over the age of 40 (Savran et al. 2018). In a study conducted in Çanakkale and Tekirdağ, it was determined that 6.6% of the participants were between the ages of 20-30, 15.4% were between the ages of 31-40, 22.2% were between the ages of 41-50, and 55.7% were over the age of 50 (Köksal et al. 2021).

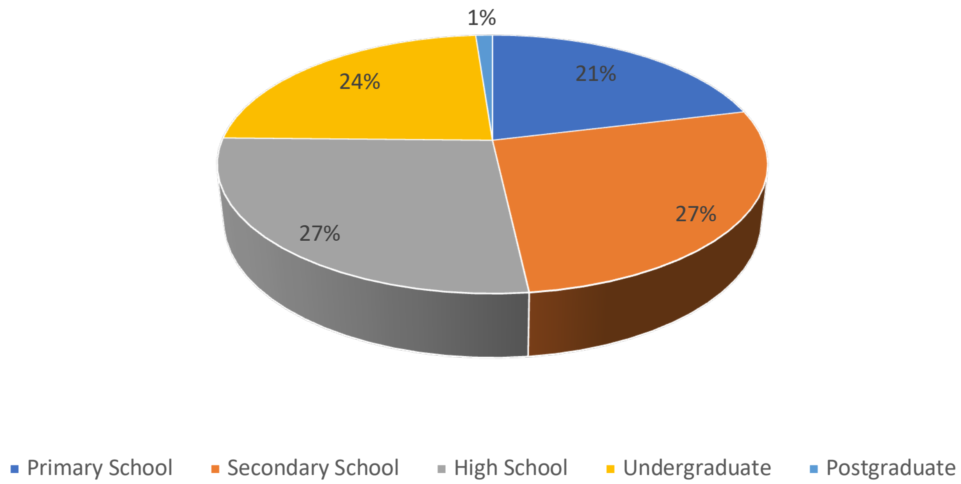

Figure 2. Educational status of farmers participating in the fair (%)

According to Figure 2, 27% of the participants attending the fair are middle school graduates, 27% are high school graduates, 24% are undergraduate graduates, 21% are primary school graduates and 1% are postgraduate graduates. Figure 3 shows the social security status of the participants attending the fair.

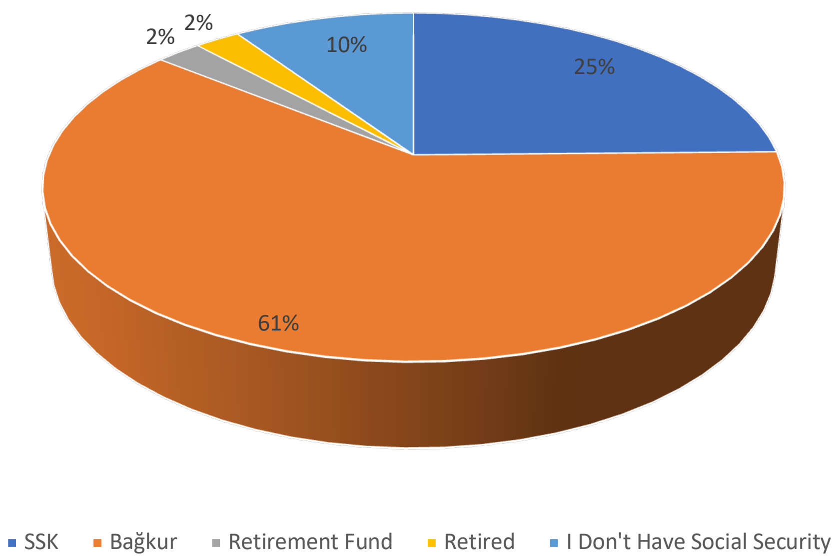

Figure 3. Social security status of farmers attending the fair (%)

According to Figure 3, when the social security status of the participants attending the fair is examined, 61% are BAGKUR, 25% SSK, 10% do not have social security, 1% are retired and 2% are pension fund. The land assets of the farmers participating in agriculture are given in Graph 4.

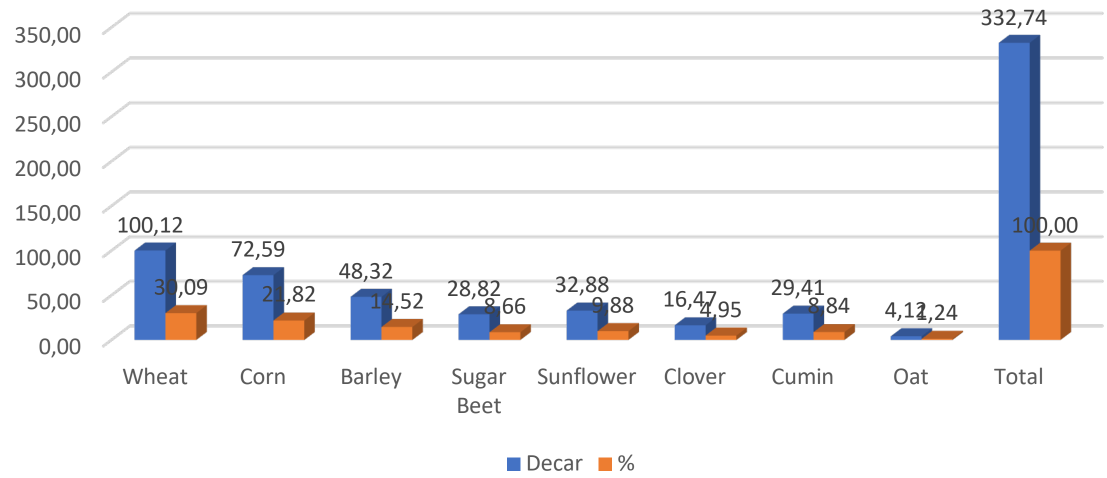

Figure 4. Land assets of the farmers attending the fair (da, %)

The total land area of the farmers participating in the agricultural fair is 332.74 hectares. 30.09% of this land asset is wheat, 21.82% is corn, 14.52% is barley, 9.88% is a sunflower, 8.66% is sugar beet, 8.84% is cumin and 2.24% is oat. The agricultural production experience of the farmers participating in the agricultural fair is 21.93 years. The reasons for the participants' participation in the agricultural fair are given in Figure 5.

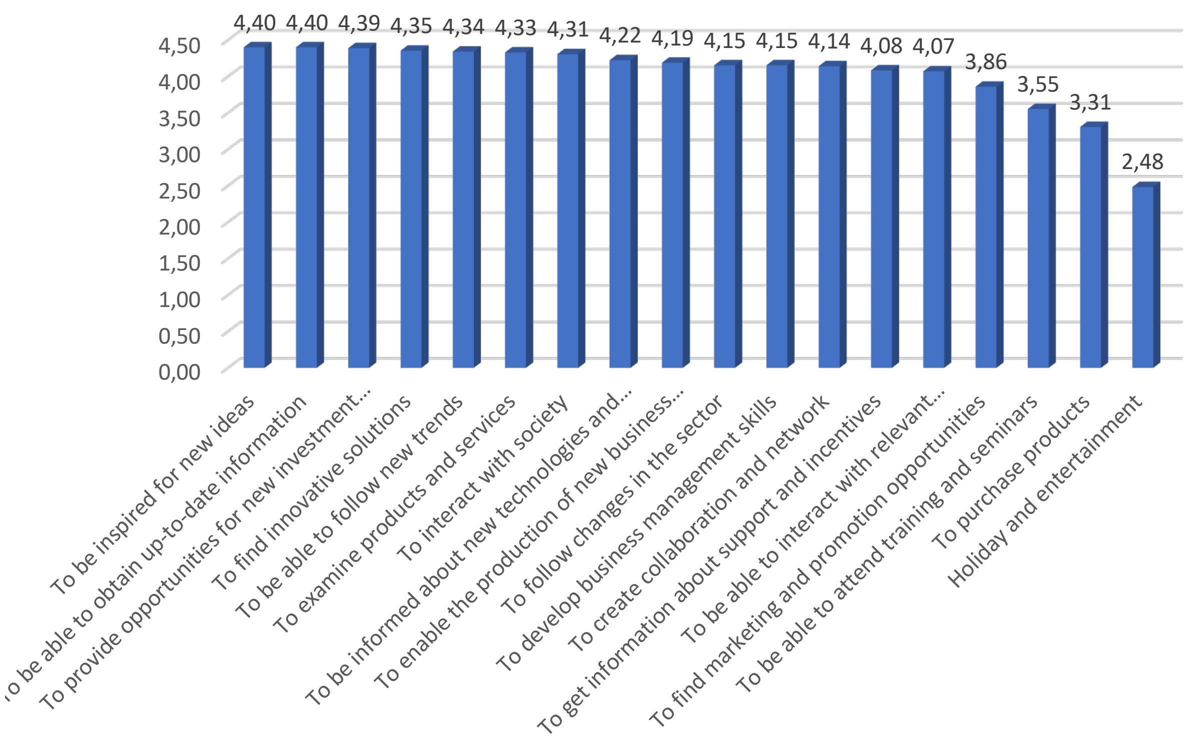

Figure 5. Reasons for the farmers' participation in the fair

When the reasons for participation of the participants attending the agricultural fair are examined, it is seen that they are; to be inspired by new ideas (4.40), to obtain up-to-date information (4.40), to provide opportunities for new investment areas (4.39), to find innovative solutions (4.35), to follow new trends (4.34), to examine products and services (4.33), to interact with the society (4.31), to be informed about new technologies and agricultural innovations (4.22), to enable the generation of new business ideas in agricultural issues (4.19), to follow changes in the sector (4.15), to develop business management skills (4.15), to establish cooperation and network (4.14), to get information about support and incentives (4.08), to interact with relevant organizations (4.07), to find marketing and promotion opportunities (3.86), to participate in training and seminars (3.55), to purchase products (3.31) and to have fun and have fun (2.48). In a similar study, the vast majority of producers (72.9%) who heard about the fair location and time from social media, roadsides, or posters were found to have the reason for attending fairs as seeing new technologies and learning more about these technologies (Köksal et al. 2021). Fairs are temporary or regular places where agricultural products are sold freely (Dickson 1966). The satisfaction of the participants attending the agricultural fair with the agricultural fair is quite important. Figure 6 shows the satisfaction of the participants attending the agricultural fair with the agricultural fair.

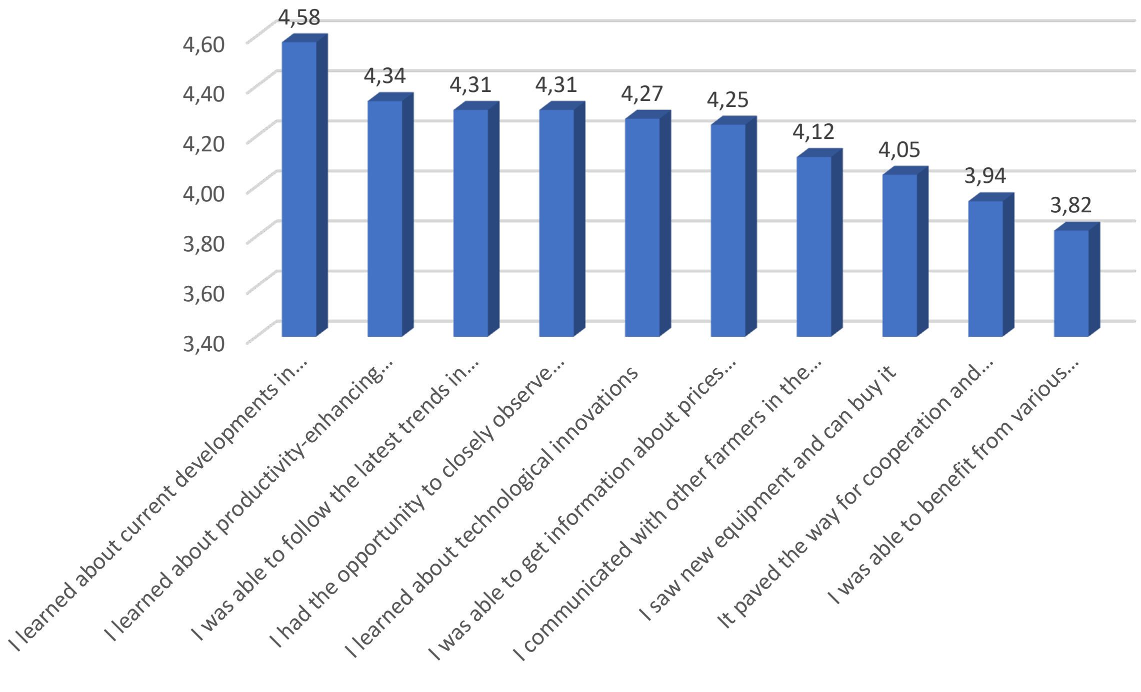

Figure 6. Farmers' satisfaction with the agricultural fair

When the satisfaction levels of the participants attending the agricultural fair were examined, it was determined that they were satisfied with the following issues: learning about current developments in the agricultural sector (4.58), learning about products that increase productivity (4.34), being able to follow the latest trends in the agricultural sector (4.31), being able to closely observe the latest developments in agricultural technology and innovations (4.31), learning about technological innovations (4.27), being able to get information about prices and conditions by directly contacting sellers and suppliers (4.25), communicating with other farmers in the sector and sharing their experiences (4.12), being able to see and purchase new equipment (4.05), preparing the ground for cooperation and partnership opportunities (3.94) and being able to benefit from various pieces of training and seminars (3.82). In a similar study, a large portion of the participants expressed their satisfaction and stated that they would attend the fair again (de Meneses et al., 2007). In a similar study, it was found that participants enjoyed it (5.23), had a good time (5.14), and were satisfied because it was exciting (5.14) and exciting (4.25) (Acharya and Lillywhite 2021).

4. Conclusions

The research results showed that the farmers participating in the agricultural fair were between 30 and 49 and were high school and middle school graduates. The majority of them have social security status as Bağkur. The most produced products are wheat, corn, and barley. The agricultural production experience of the farmers participating in the agricultural fair is 21.93 years. When the reasons for the participation of the participants attending the agricultural fair were examined, it was determined that they attended to be inspired by new ideas (4.40), to obtain up-to-date information (4.40), to provide opportunities for new investment areas (4.39), to find innovative solutions (4.35), to follow new trends (4.34), to examine products and services (4.33), to interact with the society (4.31), to be informed about new technologies and agricultural innovations (4.22), to enable the generation of new business ideas in agricultural matters (4.19), to follow changes in the sector (4.15), to develop business management skills (4.15), to establish cooperation and network (4.14), to receive information about support and incentives (4.08), to interact with relevant organizations (4.07), to find marketing and promotion opportunities (3.86) and to attend training and seminars. When the satisfaction levels of the participants attending the agricultural fair were examined, it was determined that they were satisfied with the following: learning about current developments in the agricultural sector (4.58), learning about productivity-enhancing products (4.34), being able to follow the latest trends in the agricultural industry (4.31), having the opportunity to closely observe the latest developments in agricultural technologies and innovations (4.31), learning about technological innovations (4.27), being able to get information about prices and conditions by directly contacting sellers and suppliers (4.25), communicating with other farmers in the sector and sharing experiences (4.12), being able to see and purchase new equipment (4.05), preparing the ground for cooperation and partnership opportunities (3.94), and being able to benefit from various pieces of training and seminars (3.82). In a similar study, it was determined that a large portion of the participants at the fair would return by expressing their satisfaction. This situation shows that the education levels of the farmers involved in agricultural production are generally at a medium level and that the farmers are satisfied with the agricultural fair. Rapid developments have also emerged in industry and technology with the globalization of the world. Fairs have a very important share in the introduction of these technologies. In addition, fairs have become the greatest dynamic of the need for socialization that development has limited. Therefore, efforts should be made to increase the number of participants in agricultural fairs, and farmers' participation in fairs should be increased. In particular, farmers participating in agricultural fairs should be provided with access to financial resources to purchase the technologies they see at the fair.

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Obtaining Haploid Plants Via Anther Culture in Some Eggplant Varieties

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HIGHLIGHTS

- Modified callus culture was detected in eggplant
- Regeneration medium varies depending on the species.
- Determination of ploidy of plants obtained from anther culture is important.

Abstract

In plant breeding studies, anther culture is used to breed hybrid varieties, to transform tetraplaid plants that can be obtained through interspecific somatic hybridization into fertile dihaploid plants, and in recent years, to obtain diploid in protoplast fusion of haploid embryogenic calli obtained from anther culture. The frequency of obtaining haploid plants in anther culture depends on many factors such as the variety, the season in which it was taken and the use of suitable media for regeneration. It was aimed to determine the most suitable regeneration medium for anther culture in Aydın Black and Kemer eggplant varieties, which are widely grown in our country. In the anther culture study, C (callus), R (regeneration) and V3 media recommended by Dumas de Valux et al. (1982) were used as nutrient media. However, as C (callus) medium, Dumas de Vaulx et al. (1982) 3 different doses of 2,4 D, Kinetin and sucrose of the C medium reported were tested. The highest plant yield (36.4%) of the Aydin Siyahı variety was obtained from the modified Dumas de Vaulx et al. (1982), from 1 mg/l 2.4-D +1 mg/l Kinetin + 120 g/l sucrose medium, the highest plant yield (33.8%) of the Kemer variety was reported by Dumas de Vaulx et al. (1982), obtained from 5 mg/l 2.4-D + 5 mg/l Kinetin + 120 g/l sucrose medium. Of the 79 plants obtained from anther culture and whose ploidy level was examined, 60 were determined as haploid, 13 as diploid, 4 as triploid, 1 as tetraploid and 1 as mixoploid.

Keywords: *Solanum melongena* , anther culture, haphoid plant, callus medium

1. Introduction

Eggplant is the third most important vegetable in terms of production within the Solanaceae family, after potatoes and tomatoes, and is also very valuable in terms of its vitamin and mineral content. Eggplant constitutes approximately 5% (59 million tons) of the world's total vegetable production (1173 million tons). According to FAO 2022 data, 93% of eggplant production is produced in Asia and 6% in Africa, Europe and America (FAO 2024). According to Gebeloğlu and Ellialtıoğlu (2022), there are 3 cultured species (*Solanum melongena, Solanum aethiopicum* and *Solanum macrocarpon*). Anther culture; It is the name given to the phenomenon of isolating anthers containing immature microspores from the buds and placing them in

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artificial nutrient media under *in vitro* conditions, where haploid embryos are obtained from the microspores (Ellialtıoğlu et al. 2012). Anther culture is a technique used in eggplant since the 1980s, and the haploid plants obtained are used in F1 hybrid breeding and mutation breeding. (Alpsoy and Şeniz, 2007; Seguí-Simarro, 2016; Rotino, 2016). Obtaining homozygous plants (DH) used in F1 variety breeding from haploid plants obtained from anther culture shortens the breeding period. However, the production of haploid plants varies depending on the species, the period in which microspores are collected, and the physical and chemical structure of the regeneration environment (Calabuig-Serna et al. 2020; Salas et al. 2012). The anther culture technique has been used in eggplant breeding for more than 40 years and very few successful results have been obtained. (Khatun et al. 2006; Kumar et al. 2003; Alpsoy and Şeniz 2007; Salas et al. 2011; and Başay and Ellialtıoğlu 2013).

In eggplant anther culture studies, it has been determined that the most suitable bud harvesting time for *Solanum melongena* is at the last stage of the single-nucleated microspore, that is, morphologically, the petal appears in a bitter yellow-yellow color and 2 mm. (Vural et al. 2019; Salas et al. 2012; Mir et al. 2021).

The aim of this study is to analyze Kemer and Aydın Siyahı varieties by Dumas de Vaulx et al. (1982) reported that the C medium was modified and 3 different doses of 2,4 D, Kinetin and sucrose were tested to increase the formation of embrogenic plants. The ploidy levels of the obtained plants were determined by flow-cytometry method.

2. Materials and Methods

Research; It was carried out in Çukurova University Faculty of Agriculture Department of Horticulture Tissue Culture Laboratory and Research and Application Field, Çukurova University Biotechnology Center and Batı Akdeniz Agricultural Research Institute Directorate (BATEM) Vegetable and Ornamental Plants Department Application Field and Laboratory.

2.1. Plant material

The seeds of the plant materials used in the study were obtained from the Batı Akdeniz Agricultural Research Institute (BATEM). Seeds *of Solanum melongena* cv Kemer and Aydın Siyahı eggplant varieties, which are the most grown in greenhouse and open air in our country, were used.

2.2. Collecting flower buds and transferring them to the regeneration medium

The anthers of *Solanum melongena* (bitter yellow to yellow, that is, the period when the petal appears 2 mm) were taken and sterilized at the last stage of the single-nucleated microspore (Figure 1.). The collected buds were kept in 70% ethyl alcohol for 5 minutes in a sterile cabinet, then in 1% active sodium hypochlorite for 15 minutes and rinsed 3 times with sterile pure water. Sterilized anthers (3 different 2,4 D Kinetin and sucrose doses of the C medium reported in Dumas de Vaulx et al. (1982) were tested) were placed in the C medium whose contents are given in Table 1-2 and kept in the incubator in the dark at 35 ^{0}C for 8 days. Then, the petri dishes were placed under 16-hour light/8-hour dark conditions at 25 ^{0}C. Anthers were transferred from C medium to R medium after the 13th day. When embryos or plants were formed in R medium, they were transferred to V3 medium. Observations and counts of callus and plant development were made from anthers. (Figure 2.). The resulting plants were transferred to glass jars containing V3 medium before acclimating them to the external environment. Then, the developing plants were planted in closed plastic boxes of 40x60x30 cm (width, height, width) by spraying them with a perlite-peat mixture (1/1 v/v) fungicide (Figure 3.). The plastic boxes were kept in the growth room for 1 week and gradually acclimated to external conditions in greenhouses with a misting system.

Solanum melongena cv Aydın Siyahı   *Solanum melongena* cv Kemer

Figure 1. Selection of suitable buds for anther culture in *Solanum melongena*

Table 1. Contents of C, R, V3 nutrient media (mg/L)

	C	R	V3		C	R	V3
Macro nutrients				**Vitamin and amino acids**			
KNO_3	2150	2150	1900	Myo-inositol	100.00	100.00	100.00
NH_4NO_3	1238	1238	1650	Pyrodoxin HCl	5.500	5.500	5.500
$MgSO_4$-$7H_2O$	412	412	370	Nicotinic acid	0.700	0.700	0.700
$CaCl_2$-$2H_2O$	313	313	440	Thyamine HCl	0.600	0.600	0.600
KH_2PO_4	142	142	170	Calcium panthotenate	0.500	0.500	0.500
$Ca(NO_3)_2$-$4H_2O$	50	50	-	Vitamin B_{12}	0.030	-	-
NaH_2PO_4-H_2O	38	38	-	Biotin	0.005	0.005	0.005
$(NH_4)_2SO_4$	34	34	-	Glycin	0.100	0.100	0.200
KCl	7	7	-				
Micro nutrients				**Chelated Irons**			
$MnSO_4$-H_2O	22.130	20.130	0.076	Na_2-EDTA	18.65	18.65	37.30
$ZnSO_4$-$7H_2O$	3.625	3.225	1.000	$FeSO_4$-$7H_2O$	13.90	13.90	27.80
H_3BO_3	3.150	1.550	1.000				
KI	0.695	0.330	0.010				
Na_2MoO_4-$2H_2O$	0.188	0.138	-				
$CuSO_4$-$5H_2O$	0.016	0.011	0.030				
$CoCl_2$-$6H_2O$	0.016	0.011	-				
$AlCl_3$-$6H_2O$	-	-	0.050				
$NiCl_2$-$6H_2O$	-	-	0.050				

Table 2. Plant growth regulators and their concentration

Growing medium	Plant growth regulators		Sucrose	Agar
	2.4-D	Kinetin		
	5*	5*	120**	7**
C	1*	1*	120**	7**
	0.01*	0.01*	30**	7**
R	-	0.01*	30**	7**
V3	-	-	30**	7**

* mg/L, ** g/L

2.3. Ploidy level analysis

Leaf samples from plants obtained from anther culture studies (80 plants, including the control plant) were ranked as ploidy with the flow cytometry device at Alata Horticultural Research Institute, according to Tuna (2014). Flow cytometry analyzes were performed in accordance with the kit procedure of the relevant device. Approximately 15 µg of tissue taken from young leaves of plants consisting of anthers was used. Plant tissues were chopped thoroughly with a razor blade after adding 0.5 ml of chopping buffer (Partec HR-A) using one-sided scalpels to remove cell nuclei. Chopped samples were filtered with a 30 µm permeability filter, then

Partec HR-B solution containing DAPI (4',6-diamidino-2-phenylindole) was added and incubated at room temperature for 5 minutes. As a result of incubation, the nuclear DNA content of the DAPI-stained nuclei of the leaves of the Kemer eggplant variety belonging to the control application was measured by UV LED-induced nuclear fluorescence at a wavelength of 365 nm in the Partec CyFlow Space flow cytometer. For each leaf sample, 1000-3000 nuclei were analyzed. The ploidy levels of the samples were determined by comparing them with the average radiation intensity value given by the reference nuclear DNA amount. (Figure 4.).

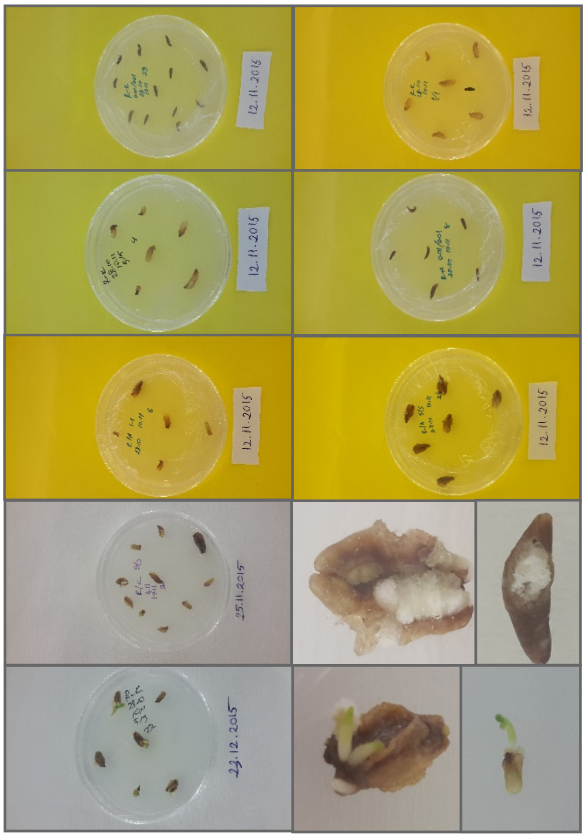

Figure 2. Plant development from anthers

Figure 3. Transferring plants consisting of anthers to jars, outdoors and land

Figure 4. Flow cytometry analysis

3. Results

In the anther culture studies in the fall of 2015, the anther development rate of the Aydın Siyahı variety was 75.2% and that of the Kemer variety was 72.6% in C (callus) medium to which 0.01 mg/l 2.4-D + 0.01 mg/l

Kinetin + 30 g/l sucrose was added. The highest callus development among the cultivated antes was 3.3% in the Aydın Siyahı variety, while it was 2.1% in the Kemer variety. Similarly, the highest embryo formation (4.23%) and plant yield (3.78%) were obtained from the Aydın Siyahı variety. (Table 3.).

In C (callus) medium with 1 mg/l 2.4-D + 1 mg/l Kinetin + 120 g/l sucrose, the anther development rate of the Aydın Siyahı variety was 82.9% and that of the Kemer variety was 77.9%. Callus development of the Aydın Siyahı variety was 34.7%, and that of the Kemer variety was 21.6%. The highest embryo formation (54.2%) and plant yield (36.4%) were obtained from the Aydın Siyahı variety. The embryo formation rate of the Kemer variety in this medium was found to be 21.5% and the plant formation rate was 14.1%. (Table 4.).

It was determined that the anther development rate of Aydın Siyahı variety was 85.5% and Kemer variety was 78.6% in C (callus) medium supplemented with 5 mg/l 2.4-D + 5 mg/l Kinetin + 120 g/l sucrose. Callus development rate was 53.1% for Aydın Siyahı variety and 34% callus rate was obtained for Kemer variety. The highest embryo formation (35.7%) and plant yield (38.8%) were obtained from the anthers of the Kemer variety. It was determined that the embryo formation rate of the Aydın Siyahı variety in 5/5 medium was 29.1% and the plant formation rate was 28.1%. (Table 5.).

High success was achieved in both direct plant formation (Figure 5.) and indirect plant formation (Figure 6.) from anthers taken from eggplants grown in the greenhouse during October in the 2015 fall period. The number of plants obtained from anther culture transferred to vials was 501, and the number of plants transferred to the field was 90 (Table 6.). While no plants were obtained from the Kemer variety in the 0.01/0.01 application, 19 plants from the Aydın Siyahı variety were transferred to *in vitro* medium acclimatization vials and 6 of them were transferred to the greenhouse. The highest number of plants transplanted into both the viols (171 plants) and the field (27 plants) was obtained from the 1/1 application of the Aydın Siyahı variety. This was followed by 5/5 application of the Kemer variety (124 plants to the viols and 22 plants to the field, respectively).

The ploidy level obtained from anther culture was determined as 60 of the 79 plants examined, 60 as haploid, 13 as diploid, 4 as triploid, 1 as tetraploid and 1 as mixoploid. Of the plants whose ploidy level was determined, 26 of them were obtained from Aydın Siyahı 1/1, 20 from Aydın Black 5/5, 23 from Kemer 5-5, 8 from Kemer 1/1 and 2 from Aydın Siyahı 0.01/0.01 application.

Table 3. Results obtained from anther culture on 0.01/0.01 medium

Varieties	Number of cultured anthers	Anther development		Frequency of calli formation		Frequency of embryo formation		Plant formation	
		Number	%	Number	%	Number	%	Number	%
Aydın Siyahı	899	676	75.2	22	3.3	38	4.23	34	3.78
Kemer	1338	971	72.6	28	2.1	17	1.27	1	0.07

Table 4. Results obtained from anther culture on 1/1 medium

Varieties	Number of cultured anthers	Anther development		Frequency of calli formation		Frequency of embryo formation		Plant formation	
		Number	%	Number	%	Number	%	Number	%
Aydın Siyahı	936	776	82.9	325	34.7	507	54.2	341	36.4
Kemer	1290	1005	77.9	278	21.6	277	21.5	182	14.1

Table 5. Results obtained from anther culture on 5/5 medium

Varieties	Number of cultured anthers	Anther development		Frequency of calli formation		Frequency of embryo formation		Plant formation	
		Number	%	Number	%	Number	%	Number	%
Aydın Siyahı	922	788	85.5	490	53.1	268	29.1	171	28.1
Kemer	1323	1040	78.6	450	34.0	472	35.7	394	33.8

Table 6. Transferring plants obtained from anther culture to the external environment

Varieties	C medium	Number of plants transferred to vials	Number of plants transferred to the greenhouse
Aydın Siyahı	**0.01/0.01**	19	6
	1/1	171	27
	5/5	115	22
Kemer	**0.01/0.01**	-	-
	1/1	72	13
	5/5	124	22
Total		**501**	**90**

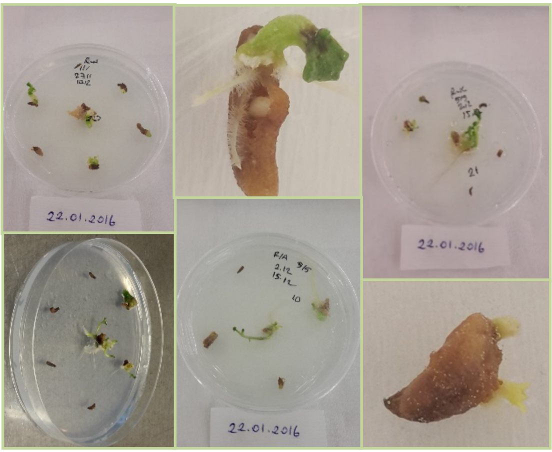

Figure 5. Direkt androgenesis

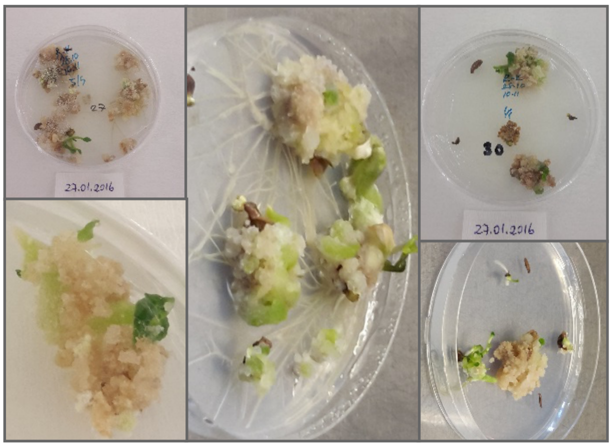

Figure 6. Indirect androgenesis

4. Discussion

Başay et al. (2010) determined that anther culture resulted in 14.29% embryo formation in the Bonica F1 variety, while anther culture was not successful in *S. torvum* and *S. sodomeum* species. They also determined that, in addition to the genotype effect in anther culture, the growing conditions of the donor plant are an important factor affecting the result obtained from anther culture. Alpsoy and Şeniz (2007) obtained 3.67% of plants from the Urfa Yerlisi variety by anther culture. Başay et al (2011) claimed that embryo formation was higher in anther culture established with buds obtained from eggplants grown in summer.

In previous studies carried out to establish an anther culture protocol in eggplant, although callus was obtained, transformation into plants and haploid plant production could not reach the desired level. It should be said that the factors affecting the success of anther culture in eggplant are the variety, the growing season of the donor plant and, perhaps most importantly, the choice of growth regulator and sucrose dose in the regeneration medium. Because the anthers placed in the same growing environment under the same conditions could not turn into plants only because the amount of hormones and sucrose were lower. While 394 plants of Kemer variety were obtained in the medium containing 5 mg/L 2.4-D + 5 mg/L Kinetin + 120 g/L sucrose, 0.01 mg/L 2.4-D + 0.01 mg/L Kinetin + 30 g/L The fact that only one plant from the Kemer variety was obtained in the medium containing sucrose proves this.

Embrogenic calli formed in anther culture are valuable as a source of somatic hybridization between species. Kashyap et al. (2003) reported that protoplast fusion used in somatic hybridization was used to transfer beneficial traits in interspecific hybridization in case of sexual incompatibility in eggplant. They emphasized that one of the most important advantages of the somatic hybrid is that, in addition to nuclear properties, cytoplasmic properties, which are of economic importance, can be transferred to the hybrid. In this context, embrogenic calli obtained from anther culture will allow somatic hybridization in interspecies hybridizations.

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Review Article

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Smart Agriculture Blockchain Applications

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HIGHLIGHTS

- Blockchain can revolutionize agriculture by enhancing transparency, traceability, and efficiency in the food industry.
- Blockchain enables secure tracking of product movement, ensuring data and food safety, and boosting consumer confidence.
- Real-time data from blockchain helps farmers make informed decisions on crop yields, weather, soil health, and animal welfare.
- Smart contracts on blockchain can automate insurance payouts, optimize soil health, create decentralized markets, and support environmentally friendly farming practices.

Abstract

Smart Agriculture is a combination of AI, Cloud Computing, and IoT that revolutionizes farming efficiency and sustainability. It successfully addresses the developing worldwide request for food production through expanding crops, optimizing inventory management, minimizing food waste, and improving the safe consumption of food. Precision agriculture, facility agriculture, and order agriculture form the core components of smart agriculture. Each one of them concentrates on specific areas of farming processes, altogether contributing to enhancing farm productivity and efficiency. The integration of blockchain technology further amplifies these benefits. Blockchain's decentralized data storage ensures data integrity and accessibility while mitigating risks associated with centralized systems. In supply chain management, blockchain enhances logistics, quality control, and risk mitigation, while in livestock management, it facilitates welfare tracking, secure identification, and grazing oversight. This study presents an in-depth review of blockchain-based smart agriculture implementations, emphasizing areas such as supply chain management, food safety, traceability, and stock management. These domains have demonstrated substantial benefits from blockchain integration. While previous research has explored various aspects of smart agriculture, an increasing number of studies highlight the supply chain as a key area of focus. The paper also highlights emerging opportunities, including the development of hybrid blockchain models to balance transparency and scalability. Additionally, blockchain-based auditing systems are identified as a

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promising tool to promote environmentally sustainable farming practices. Addressing these advancements can ensure sustainable food production, improve data management, and foster eco-friendly agricultural methods. This research underscores the transformative potential of blockchain in smart agriculture and provides a roadmap for future exploration and innovation, paving the way for sustainable and efficient farming practices.

Keywords: Blockchain; Food safety; Food traceability; Smart agriculture; Supply chain

1. Introduction

Smart Agriculture is an emerging technology that involves the integration of Artificial Intelligence (AI), Cloud Computing and the Internet of Things (IoT) in farming processes to enhance both productivity and sustainability. The fast-growing global population has led to a surge in demand for food production, making smart agriculture crucial. According to the Food and Agriculture Organization (FAO), food production must increase about 70% to sustain more than 9.1 billion people by 2050. For example, the imports of cereal products into the developing countries must increase three times to reach 300 million tons by 2050, thus the production amount in those countries needs to raise by 100% (High-Level Expert Forum, 2009). Smart agriculture can help close this gap by increasing crop yields, reducing waste, improving efficiency, and enhancing food safety.

The World Resources Institute's (WRI) research on sustainable food for the future, as outlined in research (Searchinger et al. 2018), highlights the need for the implementation of several solutions together to achieve food sustainability. Smart agriculture can offer multiple solutions presented in the WRI research. It can help reduce food loss and waste, avoid competition for crops and land, grow livestock and pasture productivity, manage water and soil, adapt to climate change, and improve manure management.

The components of smart agriculture include precision agriculture, livestock and free-range monitoring, smart irrigation, supply chain management, information storage, crop insurance and product distribution. These components constitute Cyber-Physical Systems (CPS), which integrate physical devices with computing systems to optimize farming processes.

The integration of blockchain technology into smart agriculture is a promising solution to address many problems in the agriculture industry. In the past decade, researchers have proposed many systems for smart agriculture that utilize blockchain technology. The goal behind integrating blockchain technology with smart agriculture is to create a transparent, secure, and tamper-proof system that can track the entire lifecycle of food production, from farm to table.

There are three main sectors—agriculture, food processing, and distribution— primarily responsible for gathering data on food items. Consumers increasingly seek traceability of food products throughout the supply chain, emphasizing food quality. Supply chain entities are now seeking to earn consumers' trust by providing accurate information, adhering to standards of credibility, integrity, and quality. Regulatory bodies have introduced standards to enhance transparency and traceability in the food supply chain. A shift from centralized to distributed systems is underway to leverage benefits such as fault tolerance, scalability, and improved storage (L.B. 2022).

In smart agriculture, many surveys have been conducted over the past decade. Krithika L.B. (L.B. 2022) concentrated on existing research within specific subfields of agriculture, including smart agriculture. Other surveys have examined technology acceptance in smart agriculture (Thomas et al. 2023). As this field continues to evolve, researchers are increasingly directing their focus towards the implementation of systems such as the Internet of Things (IoT) in shaping the future of smart agriculture (Ahmed et al. 2022; Quy et al. 2022; Shaikh et al. 2022; Sinha and Dhanalakshmi 2022). However, this integration raises significant security concerns, prompting researchers to delve into the associated security and privacy challenges in smart agriculture (Ahmadi 2023; Basharat and Mohamad 2022). Moreover, some researchers have explored the potential applications of blockchain in the context of smart villages (Kaur and Parashar 2022). This paper offers a comprehensive overview of the constituents of smart agriculture, with particular focus on the relationship between smart agriculture and blockchain technology. Furthermore, it highlights the advantages of integrating blockchain technology into smart agriculture and provides insights into its potential applications within the agricultural sector. The paper also classifies blockchain applications across all domains of smart agriculture and provides a detailed discussion of their implementation.

The rest of the paper is arranged as follows. Section 2 will provide an overview of the components of smart agriculture. Section 3 explores blockchain technology and its relationship with smart agriculture. Blockchain-based smart agriculture implementations are given in Section 4. Finally, Section 5 concludes the paper with a discussion of the potential future directions of smart agriculture and blockchain integration in agriculture.

2. Smart Agriculture

Among all industries, agriculture stands out as one of the most crucial. Its production is vital for the economy and plays a pivotal role in ensuring defense, nutrition, and health for populations. Moreover, agricultural production is indispensable for the planet's sustainability. With the world's population increasing daily, the demand for agricultural products is on the rise (Alam 2023).

Bogoviz et al. (Bogoviz et al. 2023) explained the disparities between traditional and smart agriculture. Farmers adhering to traditional methods for crop sowing, cultivation, and harvesting often struggle to efficiently utilize water resources and human labor. For instance, different crops require distinct watering schedules and methods. Advancing technologies, such as wireless sensor networks, enable the detection of water requirements, facilitating tailored water planning for different crops in a field. The utilization of microelectromechanical systems (MEMs) enables precise control over water amounts. These methodologies underscore the importance of integrating intelligent systems.

Smart agriculture offers real-time monitoring capabilities, reduces reliance on human labor, and automates the detection and provision of essential resources such as water, fertilizer, and sunlight. Smart agriculture systems, incorporating ubiquitous computing, wireless ad-hoc sensor networks, radio frequency identity detection, cloud computing, data analytics, remote sensing, context-aware computations, the Internet of Things and blockchain (Kumar and Dwivedi 2023), have already permeated our daily lives (Ojha et al. 2015).

Furthermore, these systems optimize various aspects including crop development, field monitoring, greenhouse gas tracking, production management, and crop protection. However, they operate with devices characterized by low power consumption, limited memory capacity, and modest computational capabilities (Atalay 2023).

Consequently, smart agriculture is the application of advanced technologies such as remote sensing, communication, and data processing in agriculture to improve productivity. It is a rapidly growing area that can revolutionize the way agriculture has been handled from field to consumer. Smart agriculture development approaches are examined under three main categories in the literature, considering the place of agriculture and the agricultural actions taken. These are precision agriculture, facility agriculture and order agriculture (Yang et al. 2021). In Europe, order agriculture closely resembles contract agriculture (Atalay 2023).

2.1 Precision Agriculture

To enhance soil quality and productivity, farmers can implement a range of targeted interventions, a practice commonly referred to as precision farming. This is made feasible by advancements in increasingly sophisticated technologies. The term "precision" is aptly used because these cutting-edge tools allow for precise interventions to be executed at the right location, at the right time, and with exceptional accuracy, tailored to the specific needs of individual crops and areas of land (Raj et al. 2021). The emergence of smart farming and precision agriculture represents a groundbreaking innovation within the agricultural sector.

These technologies automate farming processes with the goal of achieving both high yield quantities and quality, thereby promoting food sustainability (Kwaghtyo and Eke 2023).

Precision farming is carried out in rural areas. Because agriculture is done outdoors it is affected by climatic conditions. This agricultural approach optimizes the timing and amount of water, fertilizer, seed, and pesticide with a focus on increasing the targeted product yield and protecting the agricultural ecological environment. Precision Agriculture utilizes data from multiple sources to optimize the farming process by utilizing sensors to keep track of any environmental changes, and then using machine learning algorithms to examine the data gathered. This provides valuable information on the condition of crops, helps determine the optimal approaches for planting, watering, and fertilizing, and reduces environmental impact.

Wireless sensor networks (WSNs) play a key role in this farming approach. The agricultural data (environmental data, crop development and health status data) collected from the different low-energy sensors lowers the risks in the precision farming process and enables the implementation of effective agricultural management (Srbinovska et al. 2015). Integrating wireless sensor networks lies at the core of precision farming, by facilitating real-time monitoring and data-driven decision-making in agricultural practices (Dangi 2004). In addition to remote sensing methods, Geographical Information Systems (GIS) and Global Positioning System (GPS) data are used extensively in the precision agriculture approach (Ferrag et al. 2020).

Data from the field, GIS and GPS are processed to obtain useful information. In the data processing, learning-based (Machine learning, Deep learning, etc.) methods are used (Yang et al. 2021). The information obtained because of the process is used in product and production management.

2.2 Facility Agriculture

Facility agriculture represents a novel production system that utilizes artificial technology to regulate the growth environment of crops, aiming to achieve efficient production (Bi and Liu 2023). In facility agriculture, the focus is on enhancing productivity within industrial settings. In these contexts, developmental areas oversee productivity across larger time intervals and broader plantations compared to precision agriculture. The main factors in facility agriculture include capital, technological resources, and workforce. Within these facilities, various environmental factors are artificially controlled. Synthetic processes can influence planting, cultivation, and other agricultural activities (Atalay 2023).

Facility agriculture is usually carried out in industrial areas close to the city. It aims to grow high quality products efficiently. To meet the demands and needs of people in the developing world, it makes it possible to grow the desired product in controlled environments without being affected by environmental and seasonal limitations (Vijay Hari Ram et al. 2020). As in precision agriculture, remote sensing systems are used extensively.

Horticultural and animal husbandry works done using similar technologies and systems suitable for facility agriculture are also evaluated within this scope. Any product can be grown in the facility by meticulous control of temperature and air pressure, illumination, irrigation, and fertilization, using forecast models developed using historical data of the product to be grown in facility agriculture.

The most typical example is smart greenhouses. They are commonly utilized for the cultivation of vegetables, fruits, and flowers. Currently, the main sensors used encompass environmental and plant sensors. Environmental sensors typically include temperature, humidity, soil moisture, and carbon dioxide sensors (Sun et al. 2023). This approach is also used in the fields of aquaculture, plant factory, poultry and livestock breeding with the help of different sensors and specialized control systems (Yang et al. 2021).

Smart Greenhouses are automated environments that use sensors and control systems to regulate temperature, humidity, light, and nutrients. This technology ensures that plants receive the optimal conditions for growth and reduces the need for manual labor.

Livestock Breeding and Monitoring uses technology to monitor livestock health and behavior. This involves using sensors attached to animals to monitor their movement and vital signs and analyze data to detect early signs of illness and optimize food and water consumption.

2.3 Order Agriculture

The order agriculture model is implemented to integrate technological innovations into human life. In this approach, agricultural infrastructure models tailored to specific geographical regions are strategized, utilized, monitored, and overseen. These region-specific agricultural activities can be optimized by effectively managing the supply chain, integrating appropriate technologies into relevant socio-economic units, and enhancing crop storage conditions.

Solutions for industrial applications are offered by order agriculture, derived from developments in precision and facility agriculture. For instance, when optoelectronic sensors are used to monitor and analyze weed and pest growth around a specific plant, it is categorized under precision agriculture. In facility agriculture, this mechanism is implemented and evaluated to routinely monitor a specific plantation. In order agriculture, the objective is to minimize pesticide use to mitigate damage to the ecosystem (Atalay 2023).

Although product efficiency can be increased using advanced technologies, this alone cannot gain commercial value (Dalohoun et al. 2009). To prevent unconscious production and to minimize production risks, an efficient commercial model is created with the help of order agriculture, which considers the external demand for the product (Bellemare and Bloem 2018). The agricultural supply chain developed in this process.

1. It provides agricultural product transparency from field to market.
2. It prevents information imbalance between farmers and suppliers.
3. It helps to ensure the supply-demand balance in agricultural products.

It has been proposed to use the increasingly popular blockchain technology to solve the trust problem in agricultural product supply chains (Hua et al. 2018).

To implement smart agriculture, several components and requirements are necessary. These include remote sensing tools for data collection, communication systems for data transmission, data storage, and control system. Figure 1 demonstrates the data flow in a smart agriculture system.

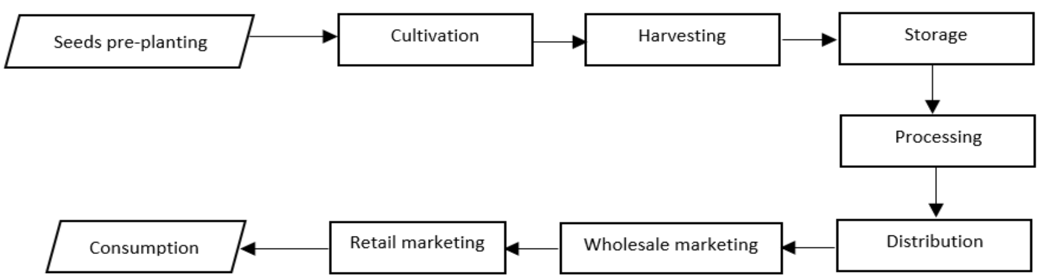

Figure 1. Data flow in food chain.

Additionally, farmers need specialized agricultural software to analyze the collected data to manage their farms depending on their needs. Smart Agriculture requires investment in technology, but it has the potential to increase crop yields and reduce resource usage.

3. Blockchain Basics

Blockchain is a distributed digital ledger technology that is designed to securely record transactions and maintain a tamper-proof record of information, which makes it resistant to fraud and hacking attempts. A blockchain consists of a series of blocks, where each block contains of a set of transactions that have been verified and recorded by the network. Figure 2 provides a simple explanation of how a transaction is added to the blockchain.

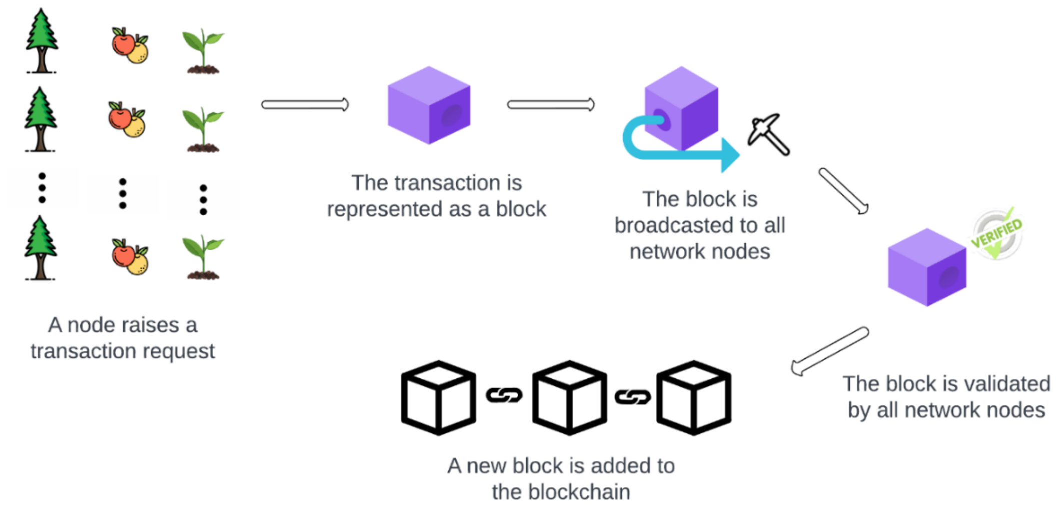

Figure 2. Transaction flow in a blockchain.

Blockchain technology serves as a robust tool for enhancing the efficiency of smart agriculture processes. In a blockchain system, users submit transactions, which are then grouped together to create a block. In a smart agriculture scenario, information about each agricultural resource, such as livestock, soil, water, plant, and seed, can be represented as a transaction. Single or multiple transactions can form a block. A block is created and verified, then it is connected to the existing chain, with the collaboration of independent parties called miners. A leader is chosen randomly among the miners to decide who will add the block to the chain. Selecting the leader can be achieved with the help of consensus algorithms. Additionally, miners must approve and accept block's proper generation before it is added to the chain.

A block includes information from the previous block to create connection between the blocks in the chain. This feature strengthens security, since modifying a single transaction would require updating all subsequent information in the chain, which is a challenging task.

Additionally, the blockchain can execute a task without third-party intervention. This is done using automated scripts called smart contracts. Smart contracts operate autonomously on the blockchain, which enables the seamless integration of these procedures during the design of the blockchain system.

Blockchain technology is highly secure and resistant to fraud. Consensus algorithms and smart contracts create a more trustworthy system by ensuring that all transactions are validated and recorded in a tamper-proof manner (Sakib 2024).

There are numerous benefits of using blockchain technology in smart agriculture. It increases transparency and immutability, improves supply chain management, and enhances food safety. Blockchain can help farmers and consumers track the origin and journey of food products from farm to consumer and ensure that the food is produced in a sustainable and ethical manner. Additionally, with its growing lists of securely linked blocks, blockchain can record sales and all data from seed planting to consumption (Patil et al. 2018).

Blockchain can help reduce fraud and corruption in the agricultural sector, leading to fair prices for farmers and improved access to markets.

4. Blockchain Platforms and Technologies

This paper explores the integration of blockchain in smart agriculture, highlighting specific platforms and technologies that address agricultural challenges.

4.1 Blockchain Platforms

1. Ethereum: Known for its smart contract functionality, Ethereum enables automated solutions for crop insurance (Omar et al. 2023), land registry (Shrivastava and Dwivedi 2023), and food traceability (Kechagias et al. 2023). This reduces dependency on intermediaries while enhancing transparency and efficiency.
2. Hyperledger Fabric: A permissioned blockchain platform, Hyperledger Fabric facilitates secure data sharing (Hu et al. 2024) and ensures transparency in supply chains. It has been widely adopted for improving accountability (Srikanth et al. 2024) and managing agricultural resources.
3. Hyperledger Sawtooth: a blockchain framework designed for enterprise use, brings transformative benefits to smart agriculture by enabling secure, decentralized, and efficient management of agricultural operations. It enhances supply chain traceability (Gkogkos et al. 2023), ensuring the authenticity and quality of agricultural products by recording every transaction on an immutable ledger. This provides transparency and builds trust among consumers, farmers, and stakeholders.
4. Multi-Chain: A blockchain platform designed to facilitate the deploying of customized permissioned blockchains. For example, the FoodFresh model (Stangl and Neumann 2023), which significantly enhances smart agriculture by enabling controlled data transparency and secure collaboration across agricultural supply chains. Multi-Chain can also help enhancing land record management in smart agriculture (Kumar et al. 2024).

4.1 Implementation Techniques

To harness blockchain effectively, the following implementation techniques have been adopted:

1. Smart Contracts: They automate processes like crop insurance payouts based on predefined conditions such as weather data or yield thresholds. For example, (Loukil et al. 2021) proposed CioSy, a blockchain-based collaborative insurance system that automates policy processing, claim handling, and payment through smart contracts, enabling peer-to-peer insurance while ensuring transparency and reducing operational costs.
2. IoT: IoT sensors combined with blockchain platforms monitor environmental conditions like temperature, humidity, and soil moisture (Ahmed et al. 2024). IoT-based aquaculture systems can leverage advanced monitoring technologies to track vital water quality parameters such as temperature and dissolved oxygen in real time, ensuring optimal fishpond conditions (Prapti et al. 2022).

5. Blockchain Applications on Smart Agriculture

Blockchain technology provides secure and temper-proof transactions without intermediaries and can transform various industries, including agriculture. There are many benefits to using blockchain technology in smart agriculture. These benefits include food safety, data transparency, traceability, and efficiency in supply chain (Yadav and Singh 2019). It also makes it possible to securely save information about the farms on blocks (Xiong et al. 2020).

In today's world, consumers are increasingly demanding more transparency in the food supply chain. They want to know where their food comes from, how it is produced, and whether it is safe to consume. However, the global food supply chain is complex, which makes it difficult to track and trace products. Blockchain technology provides a solution by creating a secure, transparent, and immutable ledger that can track the entire food supply chain. It can ensure that the food is produced and transported in compliance with regulations and ethical standards. Additionally, blockchain technology can improve farmers' livelihoods by giving them better access to sales, insurance, farm overseeing and other services.

Blockchain technology can provide transparency and traceability in the supply chain, so that farmers can track the movement of products from the farms to the consumers. This also provides consumers with information on the safety and quality of the food they are consuming, thus improving their confidence. In addition, blockchain helps farmers manage their farms more efficiently by providing them with real-time data on crop yields, weather conditions, and soil health. This data helps farmers make better decisions about crop selection, fertilization, and irrigation, and thus improving their productivity and profitability.

Accordingly, blockchain technology can be used in various areas of smart agriculture, including:

1. Production: It refers to the agricultural product that is produced using technology. Smart agriculture uses technology to produce more food and retain its sustainability.
2. Storage: It refers to the use of technology to optimize the storage of agricultural products. Smart storage can also involve optimizing inventory management and reducing waste.
3. Stock: It refers to the land, farm, livestock. Smart agriculture uses technology to manage these assets to improve productivity, sustainability, and profitability.

5.1 Production

Blockchain technology can be implemented in food supply chain and food traceability. Figure 3 shows where this technology can be implemented in food production.

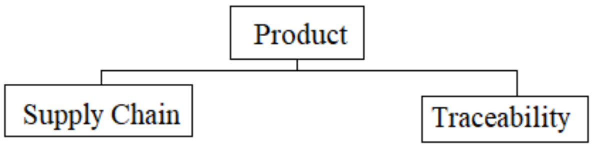

Figure 3. Areas where blockchain can be implemented in production.

5.1.1 Food Supply Chain

Supply chain is divided into two entities: organizations or individuals that are directly involved in products, services, finances, and data from seed planting to consumption (Mentzer et al. 2001). Food is one of the most important aspects that needs to be considered from a society perspective. It is the pillar of health, happiness, and economy. However, when it comes to delivering the product to consumer, the priority to consider is the security and personal safety of individuals (“Food Supply Chain Manag.” 2007). Some blockchain applications in agri-food area are:

Chatterjee et al. (Chatterjee et al. 2023) explored the integration of Internet of Things (IoT) technology within Industry 4.0, underscoring its diverse applications across sectors like banking, manufacturing, healthcare, and government. Industrial IoT (IIoT) is specifically highlighted for its role in leveraging IoT services to link existing industrial processes with emerging technologies such as smart sensors, robotics, and artificial intelligence, with a particular focus on enhancing supply chain management. The rising consumer demand for organic food products has underscored the significance of traceability and transparency in food supply chains. Consequently, regulatory bodies are advocating for enhanced standards, prompting a shift from centralized to distributed systems to bolster fault tolerance and scalability. The design of food supply chain systems is examined through the lens of a hierarchical location problem, with recent research exploring optimization strategies. Additionally, they introduced a blockchain-based food supply chain system that was tailored for the agro-food industry. Their paper emphasized the system’s advantages over traditional management methods, especially in terms of traceability and security. However, the proposed model does have some limitations, including scalability issues and a susceptibility to certain types of attacks. These limitations require future enhancements.

Mandela et al. (Mandela et al. 2023) introduced the complexities confronting agricultural supply chains in Andhra Pradesh, India, within the broader context of ensuring food safety and quality. They proposed using consensus algorithms to develop a blockchain-based query processing system, with the intention to augment transparency, accountability, traceability, and efficiency throughout the agricultural supply chain. Moreover, they underscored potential benefits, such as enhanced market access and sustainability. The study also covered precision agriculture, emphasizing its use of advanced technologies to enhance productivity and minimize waste, alongside the growing challenge of ensuring food safety. It highlights the significance of blockchain technology in addressing these challenges and bolstering food safety, traceability, and environmental sustainability. The authors identified consensus algorithms as pivotal for upholding the integrity and security of blockchain transactions, which would facilitate the establishment of dependable and transparent supply chains for smart agriculture.

In a study conducted by Leng et al. (Leng et al. 2018) they identified and discussed significant problems in the Chinese public service platform related to agriculture. and proposed a solution using public blockchain technology. This included problems such as a lack of resource matching mechanisms, low utilization rates, and suboptimal system performance. These issues all increased transaction costs and discouraged users from engaging with the platform. The authors also discussed concerns about transaction security, transparency, user privacy, and platform credibility. They suggested integrating a two-chain public blockchain system tailored for agricultural business resources into the existing platform. This integration would provide technical support, create a functional environment, and enhance the usage rate, credibility, and effectiveness of the platform while ensuring secure handling of diverse types of data.

One crucial procedure in Agri-food is quality measurement. Lucena et al. (Lucena et al. 2018) addressed the quality management of the grain throughout the transportation chain using blockchain to bring more efficiency and resilience to this process. They presented the Grain Exporters Business Network 'GEBN,' which is an enterprise that collects information from quality assurance processes and then provides data for diverse business partners of the Brazilian GEBN. It is made up of various stakeholders, such as grain producers, local credit unions, warehouse companies, trading exporters, agrochemical companies, freight forwarders, and ports authorities. The platform can assist producers to trace the products stored in warehouses.

Saberi et al. (Saberi et al. 2019) examined the application of blockchain technology for promoting sustainability within supply chains. With increasing pressure from both local and global governments and communities to achieve sustainability goals, there is a growing need to explore how blockchain can address supply chain sustainability. The authors proposed a transformation of traditional supply chains into blockchain-based systems, which involved four main entities: a registrar providing actor identification, a standards body defining blockchain guidelines and technical requirements, a certifier authorizing parties to participate in the supply chain, and several factors such as manufacturers, retailers, and customers (Project Provenance Ltd 2015). They also put forward future research suggestions to overcome barriers and promote the adoption of blockchain in supply chain management.

5.1.2 Traceability

Food traceability means following and tracing the documentation and linkage of all stages in the supply chain, both forwards and backwards, through which a food product and its ingredients move from production to distribution (FDA 2022). The utilization of blockchain in traceability systems ensures the reliability and authenticity of shared information (Tian 2016).

Researchers have been exploring the application of blockchain technology to enhance food safety. One notable study by Lin et al. (Lin et al. 2019) introduced a blockchain system to both prevent the tampering of food data and to address the shortcomings of the existing traceability systems. The authors developed a prototype system that combined blockchain and Electronic Product Code Information Services (EPICS) to trace the products. This distributed system allowed for the creation and sharing of visibility data, ensured the security of sensitive information through tamper-proof features while maintaining scalability. The integration of an enterprise-level smart contract ensured the confidentiality of business data and authenticated the identity of the enterprise. By leveraging the advantages of the EPCIS specification, which included ObjectEvent, AggregationEvent, QuantityEvent, and TransactionEvent, the proposed system demonstrated potential for effectively addressing food safety concerns.

Ferrández-Pastor et al. (Ferrández-Pastor et al. 2022) investigated the potential of integrating Internet of Things (IoT) facilities and ambient intelligence paradigms to optimize agronomic processes, with a focus on the hemp industry., Their goal was to enhance both traceability and security. They proposed a comprehensive model that amalgamates agricultural expertise, blockchain technology for value chain planning, and IoT protocols for digital traceability. The efficacy of the model was demonstrated through a proof-of-concept implementation, highlighting its ability to deliver tamper-proof and transparent traceability services. Additionally, the article underscored the significance of integrating information technologies to address consumer concerns regarding product safety, quality, and origin. Their proposed model offered numerous benefits, including the active engagement of agricultural experts, enhanced traceability, improved data security, process optimization, and cost savings through smart contracts. However, it also presented new challenges, such as ensuring seamless integration into existing systems, providing intuitive interfaces for farmers and technicians, and ensuring ongoing maintenance and updates. Overall, the article presented a promising approach to advancing traceability and resource optimization services in agricultural production processes, with the potential for future extensions and enhancements.

A study conducted by Sezer et al. (Sezer et al. 2022) discussed the critical aspects of traceability in supply chain management, underlining the pivotal role of customer trust. It pointed out the inadequacies of the existing frameworks in delivering efficient traceability, real-time data, and privacy safeguards. The article introduced a supply chain traceability framework that leveraged smart contracts to safeguard privacy from external entities. This framework incorporated a digital signature and verification mechanisms to uphold data integrity and authenticity. Thus, offering both anonymity and traceability according to user preferences. Furthermore, it discussed how blockchain technology enhances transparency and trust by securely storing transaction data in an immutable manner. The article also delved into the complexities of traceability in supply chains and stressed the need for systems that ensure product tracking while maintaining trust and privacy. The proposed framework, grounded in permissioned blockchain architecture, sought to strike a balance between anonymity and transparency while ensuring traceability and privacy through on-chain and off-chain smart contracts. Their experimental findings suggest that the framework presents a user-friendly and auditable model for supply chains. Future research endeavors include addressing space complexity using side chains, implementing lightweight blockchain architectures for IoT devices, and exploring real-world applications of the proposed framework.

Lin et al. (Lin et al. 2018) proposed a secure food traceability system that utilized blockchain technology and IoT devices to address food safety concerns. The system's goal was to track and monitor the entire food production process, from seed cultivation to selling, and to reduce human intervention using IoT devices to record and verify. In their system, a combination of the traditional Enterprise Resource Planning (ERP) legacy system and a new IoT system was employed. Mobile phones served as a portal or blockchain thin node for farm companies, logistic companies, and customers to access the data stored in the chain.

Another study by Tse et al. (Tse et al. 2017) proposed blockchain technology as a solution to improve food safety standards in response to rising concerns in China. The current food safety systems failed to meet the required standards, which resulted in products classified as unsafe for trade. To address this problem, the authors suggested blockchain to secure information within the food supply chain. They applied tailored theoretical methods and conducted a market analysis to develop an efficient and reliable solution for managing agricultural product safety in China. Through the implementation of blockchain, the study sought to enhance the quality and safety of food products in the country, mitigating potential health risks and improving the overall quality of life.

Feng Tian (Tian 2016) proposed a food safety system that used blockchain technology to achieve transparency and openness in the food supply chain. This system tracked products in real-time using logistic companies, which eliminated the need for a centralized organization to oversee food safety information. All members of the system had access to an information platform, and blockchain ensured the integrity of the food data. The system focused on two categories of agri-food: fresh fruits and vegetables, and meat. It utilized RFID technology to acquire and share data throughout the entire production process, while blockchain certified the reliability of the information shared within the system. Overall, the system provided a secure and traceable platform for all members of the food supply chain.

Caro et al. (Caro et al. 2018) evaluated the effectiveness of AgrilockIoT, a system that utilized both IoT sensing devices and blockchain technology for agricultural traceability. The system generated digital values through the IoT devices and stored them securely in a blockchain, creating transparent and unchangeable records. The study found that using a permissioned blockchain, instead of a public blockchain, significantly improved the performance of the smart agriculture system. The permissioned blockchain had lower latency compared to the public blockchain, and thus offered faster and easier operation. Additionally, the public blockchain consumed approximately 50 percent more resources, resulting in poorer performance.

In a study conducted on using blockchain technology to track wood electronically throughout the supply chain. Figorilli et al. (Figorilli et al. 2018) implemented a blockchain architecture to enable traceability of the wood supply chain, simulating processes from tree cutting to the sawmill in Italy. Open source IoT devices collected data on tree species, date, position, number of logs, and commercial information, which was stored in a centralized database using a specific forest operations app. The blockchain system allows retrieval of historical information by tracing each tree's journey. Activation of the blockchain involved an activation code and data transmission, synchronized with a remote server. Two steps were required: authorization through Azure Blockchain workbench and data formatting, verification, and writing onto the blockchain. The application ensured that no unauthorized logs were inserted and provided progress feedback during the synchronization process.

Kumar and Iyengar (Kumar and Iyengar 2017) presented a case study of the application of blockchain technology to the rice supply chain. When participants in the chain registered in the system, they had unique identities and digital profiles which were stored in the blockchain. The rice supply chain has five phases: production, procurement, processing, distribution, and retailing. Blockchain was used to ensure traceability, combat fraud, and reduce errors by documenting all events that occurred in the chain. Each time the rice changed location, the information was recorded on the blockchain, creating a permanent record of its journey from the manufacturer to the consumer. The authors demonstrated how blockchain technology enhanced product safety and improved the efficiency of the rice supply chain through comprehensive traceability, event recording, and monitoring of rice quality and security.

5.2 Storage

Food products like rice and beans must go through a series of procedures such as production, grading, storage, and transportation before reaching the market. Throughout this process any fraudulent or tampered steps could pose significant risks to food safety. Utilizing IoT for the real-time tracking of these procedures can ensure that the entire process is traceable. However, it is important to note that traditional storage methods are vulnerable to manipulation or destruction of the stored data. To address this problem, blockchain technology offers a safe and decentralized database consisting of a series of secured blocks of data. Once a block has been confirmed and incorporated into the chain, it cannot be altered unless someone has control over more than half of the nodes simultaneously. This feature guarantees the reliability of the blockchain as data storage.

The agricultural process begins with seed storage, which can significantly impact seed quality and production. Thus, it is crucial to monitor seed storage. To ensure better control of the market price, the distribution and market prices must be properly monitored. To have effective monitoring, agriproducts must be traceable from seed storage to the consumer. The availability of verifiable data for the agriproducts not only increases transparency but also enables monitoring and manipulation of the system. Addressing these challenges is essential for ensuring a consistent supply of food products without any shortages.

There have been many studies conducted in agricultural data storage to investigate the potential applications and advantages of integrating blockchain technology. For instance, Xie et al. (Xie et al. 2017) designed a secure data storage scheme for food tracking that was based on blockchain technology. In this system, agricultural products were equipped with an IoT sensor module that acquired data in real-time and uploaded it to the server. The server used a double-chain storage structure consisting of two interconnected main and secondary blockchains to automatically store the data in the blockchain. This certified that agricultural tracking data could be stored securely using blockchain, thereby ensuring better food safety.

Zhang et al. (Zhang et al. 2023) introduced a blockchain-based traceability model for the grain and oil food supply chain, tailored for its inherent complexities and challenges. An outlier detection model was developed to ensure accurate data collection from IoT devices, which exhibited excellent performance in outlier detection. A storage model that combined blockchain with database and IPFS was introduced to improve storage efficiency, and to reduce pressure on the blockchain network. A data recovery mechanism was implemented to ensure the timely recovery of lost or damaged data, which enhanced the system fault tolerance. Experimental results demonstrated the effectiveness of the proposed model, with average query latencies indicating efficient data retrieval. Finally, a blockchain-based grain and oil food supply chain traceability system was designed and implemented using Hyperledger Fabric, which allowed for multi-source data uploading, lightweight storage, and data recovery in the supply chain.

To ensure the secure exchange and storage of vast amounts of remote sensing data, Zou et al. (Zou et al. 2023) presented a decentralized system utilizing blockchain technology. Because conventional centralized systems are susceptible to attacks, there is a risk of data loss. Distributed Ledger Technology (DLT) provides security, traceability, and tamper-proof capabilities suitable for remote sensing applications. However, there were some challenges integrating remote sensing data into blockchain networks due to its large volume and spatiotemporal characteristics. To address these challenges, they proposed a multi-level blockchain architecture. Remote sensing data was stored in the IPFS network, with its hash value uploaded to the Ethereum chain for public access. This distributed data storage approach improved security, facilitated information exchange, and increased data management efficiency. Additionally, the paper suggested a data storage security solution leveraging multiple blockchains to offer accountable and distributed storage. Utilizing the Ethereum blockchain platform, the prototype system was designed and simulated, displaying its effectiveness in terms of data storage speed, traceability, security, and availability. However, some challenges remained, such as the need to encrypt data for further security enhancement.

Lin et al. (Lin et al. 2017) proposed a storage security approach using blockchain. The continued progression of Moore's Law, Kryder's Law, and Nielsen's Law, which describe the increasing speed of data processing, decreasing costs of data storage respectively, combined with increasing bandwidth, suggests that blockchain technology can play a vital role in the agricultural industry. As a decentralized network, blockchain has the potential to democratize transactions and processes in the industry, making it the next evolutionary step for traditional Information and Communication Technology (ICT) based farming systems and e-agriculture initiatives. Through blockchain technology, agricultural and environmental monitoring data can be stored in a distributed cloud. This will lead to the achievement of sustainable agricultural development with the help of transparent data and ICT.

The proposed system was used for managing and sorting food monitoring information. They put forward a model of an ICT-based system which included a blockchain infrastructure. They suggested adding water quality monitoring data into the blockchain. Miner nodes in the network contributed its equipment to validate the blockchain and compile the complete water data.

Another study by Pranto et al. (Pranto et al. 2021) proposed the use of IoT to enhance the movement of vital data within the agricultural system. The IoT devices kept an eye on the quality and state of products stored in warehouses while providing information during the cultivation process. The monitored data was then securely saved in a blockchain, and a smart contract took care of automation, event triggering, and the enforcement of necessary terms and conditions for all parties involved.

5.3 Stock

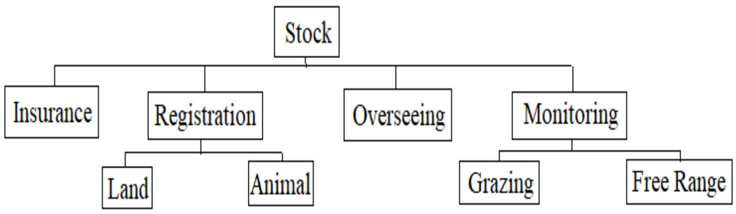

Figure. 4. Stock management in smart agriculture.

5.3.1 Crop Insurance

Farmers often do not trust insurance companies and fear delays or non-payment of claims, which makes crop insurance systems complex and challenging. However, some studies have suggested affordable and efficient crop insurance solutions that could benefit many farmers. One proposed solution was a blockchain-based crop insurance system, which provided a new infrastructure for storing, validating, and securely transferring data. Blockchain technology would ensure that the data is stored without manipulation and eliminates the need for third parties. This makes it a reliable solution for crop insurance.

Crop insurance is divided into two categories: yield protection insurance and calamity-based insurance. In yield protection insurance farmers can register a claim if their crop yield falls below a predetermined threshold. Calamity-based insurance automatically settles claims if a crop is destroyed due to a natural disaster. It does not require farmers to file a claim. Instead, when a natural disaster is recorded on the blockchain, a smart contract automatically initiates the payment process into the farmer's account.

Agricultural production is exposed to numerous uncontrollable risks. Most of the time, farmers have limited means to mitigate these risks. The most obvious being insurance, which is hindered by the lack of private sector involvement and by complicated claim procedures that discourage farmers from exploring new crops. In India, the current crop security system does not adequately address the escalating risks farmers face. To solve this problem, Iyer et al. (Iyer et al. 2021) proposed a decentralized peer-to-peer crop insurance framework to protect farmers' interests. This framework eliminated intermediaries and provided a secure, standardized, and transparent system that ensured all stakeholders had access to the necessary information. Through blockchain technology, the system promoted trust in a trustless environment and allowed for farmers and private investors to form a contract.

Omar et al. (Omar et al. 2023) presented an innovative approach to crop insurance using blockchain technology to tackle challenges like complexity, inflated costs, and a lack of trust in the conventional methods. Their blockchain-based crop index insurance solution recorded transactions and data exchanges on an immutable ledger, which ensured transparency, trust, and accountability. Smart contracts can streamline claim processing, reduce fraud and settlement delays, and lower costs by removing intermediaries. Their solution democratized crop insurance and expanded access to a wider range of farmers. It also included those in low-income countries. Their paper underscores the importance of tailoring the solution to meet the needs of smallholder farmers in developing nations and highlights the advantages of decentralization and blockchain in improving transparency and trust between farmers and insurers. The authors make their smart contract code openly available and outline plans for future work to automate additional insurance processes and tackle scalability and governance challenges within the blockchain landscape.

Jha et al. (Jha et al. 2021) proposed a decentralized platform for executing contracts and storing the results of crop insurance processes using smart contracts. This system helped insurance companies detect fraud and evaluate claims through smart contracts, which are more secure and less prone to exploitation than traditional insurance systems. Blockchain allowed for secure coordination between insurers, and records were stored on a secure distributed ledger. This made any malicious activity clear and then halted the transaction. The major stakeholders in this system included farmers, smart contracts, and insurance providers. The farmers provided personal data, crop information, and land coordinates for verification by insurance providers. Once verified, the insurance policy details were written on the blockchain as a smart contract hosted on a cloud platform, and insurance providers could verify weather conditions and determine the amount of money to be paid to the farmer in case of natural calamity.

The insurance industry is facing challenges related to the processing time, security, and settlement time of payments. However, blockchain technology can provide solutions to these problems. Bai et al. (Bai et al. 2022) proposed a novel approach that leveraged blockchain technology's immutability and integrity features to enhance the insurance process. They proposed a use case of blockchain and IoT technology to develop a transparent and secure framework that could improve processing time, security, and settlement time of payments. The proposed system sought to provide a more efficient and reliable insurance service through the reduction of the time delay in a claim settlement. The system assigned a unique ID to each participant, allowing them to read and write data on the blockchain. This made it possible for all stakeholders to upload all relevant information related to the insurance policy. To capture data from agricultural land, IoT devices and various sensors such as soil, moisture and fire sensors are then deployed. The use of IoT devices removes human interaction in the process.

5.3.2 Registration

Land registration is susceptible to tampering in various countries. Blockchain technology offers significant benefits when it comes to maintaining asset registers like property, vehicles, and contracts. Blockchain has specifically gained prominence in land registration due to its ability to address fraud concerns and provide a trusted and transparent system for storing and transferring data. By decentralizing and standardizing land registration records, blockchain reduced the need for intermediaries, enhanced trust in the transacting parties' identities, improved process efficiencies, and reduced the time and cost associated with registration (Deloitte 2018). Thus, technology must continue contributing to this field.

5.3.2.1 Land Registration

According to HernandoDe Soto out of the 7.3 billion people in the world, only around 2 billion possess legal and effective documentation confirming their ownership of an asset. The lack of legal record of ownership makes it impossible to use these assets as collateral to obtain credit or to transfer a portion of property as an investment. This implies that individuals cannot fulfill their potential to create credit, because their assets may be owned without proper documentation. Thus, HernandoDe Soto emphasizes the importance of effective land administration systems to ensure that property ownership is accurately recorded and recognized by the law (Barbieri and Gassen 2017).

In 2015, it was reported that the Government of Honduras was collaborating with Factom and Epigraph to create a land registry system using blockchain technology. This initiative sparked discussions and debates about the potential applications of blockchain in land administration (Anand et al. 2017). According to Anand et al. (Anand et al. 2017), some potential applications of blockchain technology included registering title deeds, creating time-stamped transactions, providing transparent governance tools for multiple parties, creating a tamper-proof recording system, establishing a disaster recovery system, and offering restitution and compensation in post-conflict zones.

Barbieri and Gassen (Barbieri and Gassen 2017) argue that the use of blockchain technology for land registers is still not fully understood. This is especially true when it comes to the well-established interplay between cadaster and land register, and the role of notary in the framework of preventive administration of justice. They suggested that advocates of blockchain solutions may not fully understand these aspects. Thus, from their perspective, blockchain technology appears to be useful only in the context of machine-to-machine communication at present.

Vos et al. (Vos et al. 2017) examined the potential of replacing an existing land administration system with a blockchain-based alternative. They highlighted the technical and administrative requirements that must be met for a blockchain-based land administration system to be successful. Blockchain technology can be used to archive transactions and to secure their content by storing transaction data on the blockchain. They suggested that blockchain technology could be useful in countries without a reliable electronic system for transferring ownership. However, they did note that traditional database systems may be sufficient in some cases.

In considering blockchain, several principles of Good Governance can be fulfilled. For example, the transparency and efficiency of transactions can be ensured, and a tamperproof history of transactions can be maintained. Blockchain-based land administration systems can function similarly to traditional land registry systems since they keep track of property ownership and transaction records and verify the authenticity of these records. Additionally, they can ensure the accuracy and timeliness of land transactions and prevent fraudulent activities.

5.3.2.2 Animal Registration

Cho and Lee (Cho and Lee 2019) introduced an animal administration system, that utilizes blockchain technology to distinguish between animals that are preregistered or not. This system can be implemented in various areas such as animal hospitals, pet stores, animal shelters, and pet insurance policies. N-printing technology, which is like how fingerprints are used to identify humans, can be used to identify animals. This authentication process uses nose-print recognition to identify animals and connect various clients through a blockchain network.

5.3.3 Farm Overseeing

Monitoring environmental information is vital for maintaining a healthy environment. Similarly, monitoring the agri-food environment is essential for ensuring food safety. Lin et al. (Lin et al. 2017) put forward an e-agriculture system model that utilized ICT and blockchain infrastructure for water distribution monitoring at the local and regional scale. The system added water quality monitoring data to the blockchain, which was then backed up and distributed across all nodes. Each node had a copy of the water data, and a query was created for reference purposes. The provider node could later cross-reference the data in the blockchain with the backed-up data if required.

The agricultural industry has started using IoT-based greenhouse technology that enabled remote monitoring and automation. However, the security concerns related to the large-scale and widely distributed network were still significant. To address these problems, Patil et al. (Patil et al. 2018) suggested utilizing blockchain technology to secure the emerging IoT-based greenhouse technology. The system model consisted of four groups; a smart greenhouse, an overlay network for reducing network overhead and delay, a cloud storage to store data from the greenhouse devices, and end users who own, control, and remotely monitor the greenhouse through their laptops or smartphones. The proposed architecture used a lightweight blockchain-based approach, which enhanced power consumption and benefits from private immutable ledgers. The IoT devices deployed in greenhouses act as a centrally managed blockchain, which further improved the security of the system.

Mujeye et al. (Mujeye et al. 2023) discussed the potential applications of 5G technology and IoT devices in agriculture and healthcare. Their focus was on addressing security and privacy concerns through the utilization of Blockchain technology. This study outlined a research endeavor involving Illinois State University and industry collaborators, who sought to deploy a private 5G network equipped with IoT sensors for monitoring soil moisture levels on a university farm. Additionally, the project's goal was to support underserved patients in managing chronic illnesses by remotely tracking vital signs through IoT devices. The study's primary objective was to evaluate the efficacy of Blockchain in securing communications between these sensors and healthcare providers. Furthermore, it emphasized the broader impacts of the research, including enhancing healthcare accessibility for marginalized communities and tackling agricultural issues such as soil nutrient depletion and water conservation. These efforts contributed to bolstering food security for the growing global population.

5.4.4 Monitoring

5.4.4.1 Livestock grazing

The swift expansion of blockchain technology in precision agriculture has resulted in the creation of several platforms with the potential to be used for a range of agricultural activities. For example, the AppliFarm platform, established by Neovia in 2017 (ADM 2023), enabled the provision of digital evidence for animal welfare and livestock grazing. The animal sector's livestock data could be tracked through the platform, which involved the use of linked tags placed around cows' necks to identify their grazing areas. This made it possible to collect enough data to ensure high-quality grazing for the livestock. In addition, their system could be used to ensure that monitored livestock farms adhere to animal welfare requirements. The animal welfare data is integrated into the system and accessible by stakeholders whenever they need access.

5.4.4.2 Free Range

Descovi et al. (Descovi et al. 2021) presented a case study based on blockchain of the health certification of poultry farms of breeding birds in the state of Rio Grande do Sul. They then mapped it with Business Process Model and Notation (BPMN). The presented blockchain system simplified the animal sanitary control of breeding birds and demonstrated the physical and digital flow of the process and how data is stored in the blockchain.

6. Discussion and Conclusion

Blockchain technology can revolutionize the agriculture industry by improving transparency, traceability, and efficiency of the food industry. In recent years, several studies have explored the applications of blockchain in smart agriculture, highlighting its potential to transform various areas such as product supply chain, product traceability, storage, farm, and stock management.

Agricultural data should be securely stored, if it is not protected from being maliciously tampered, many risks and drawbacks are encountered, such as affecting the smart agriculture efficiency and the potential danger of compromising data integrity. Since data is written in blocks unchangeably, blockchain enables stakeholders to securely track the movement of products from the farm to the consumer, which guarantees the safety of the data as well as the safety of the food. So, by providing consumers with information on the safety and quality of the food, blockchain can improve their confidence in smart agricultural products. Additionally, blockchain technology can be used to improve productivity and profitability. It can provide farmers with real-time data on crop yields, weather conditions, and soil health, helping them make better decisions. Blockchain could also be used to track animal health records, breeding information and genetic data, and monitor animal welfare and environmental impact. Regarding insurance, blockchain could be used to create smart contracts that automatically trigger insurance payouts when certain conditions are met, such as crop failure.

Table 1. Blockchain Applications in Smart Agriculture.

Study	Classification	Problem	Technologies Used Besides the Blockchain	The Proposed Technique	How Blockchain Becomes Beneficial
Chatterjee et al. (Chatterjee et al. 2023)	Product/ Supply Chain	The rising consumer demand for organic food products	IIoT	Blockchain-based solution for the food supply system	Data Integrity and Sharing: Immutability and Decentralization
Mandela et al. (Mandela et al. 2023)	Product/ Supply Chain	Fragmentation of land in Andhra Pradesh, India / lack of transparency, storage, and processing facilities	IoT	A blockchain-based query processing system for secure supply chain	Food Safety: Transparency, immutability, and improved traceability
Leng et al. (Leng et al. 2018)	Product/ Supply Chain	Lack of adaptive rent-seeking and matching mechanism / security and transparency of transactions and platform credibility	Double chain architecture	Public blockchain of agricultural supply chain system	Agricultural resource sharing: BC provided distributed rent-seeking and matching mechanism- improved the utilization rate of agricultural business resources and credibility of the public service platform
Lucena et al. (Lucena et al. 2018)	Product/ Supply Chain	Grain quality management	Smart contracts and IoT devices	GEBN Blockchain Business Network	Quality Management: Data integrity verification for quality management purposes / Efficiency and resilience of quality measurement in grains transportation
Ferrández-Pastor et al. (Ferrández-Pastor et al. 2022)	Product/ Traceability	Integration-related challenges in the implementation of facilities based on the IoT, embedded systems, and ambient intelligence paradigms in the hemp industry	IoT	IoT and Blockchain based model for traceability: Application in industrial hemp production	Data flow security
Sezer et al. (Sezer et al. 2022)	Product/ Traceability	Poor traceability, lack of real-time data, and lack of privacy in the supply chain	Cryptography and smart contract	TPPSUPPLY: A traceable and privacy-preserving blockchain system architecture	Real-time data, data privacy, and scalability
Lin et al. (Lin et al. 2019)	Product/ Traceability	Preventing sensitive information disclosure and data tampering	Enterprise-level smart contract / off-chain database	Food safety traceability system based on blockchain and EPCIS - management architecture of on-chain and off-chain data	Data Privacy and Integrity: Sensitive business information protection / enterprise identity verification / verification of data integrity
Lin et al. (Lin et al. 2018)	Product/ Traceability	Monitoring chemical use in farming, heavy metal contamination, low-quality raw materials, and excessive additives endanger food safety	IoT devices and smart contracts	Blockchain and LoRa IoT technology-based food traceability solution	Food Safety: Tracking and monitoring the entire food production process through verification mechanism and tamper-proof advantage
Tse et al. (Tse et al. 2017)	Product/ Traceability	Potential risks to people's health and limitations in precise traceability	N/A	Blockchain technology as a potential solution for enhancing information security	Food Safety: Immutable transaction records, automated monitoring and auditing system, and food safety and certification enhancement
Zhang et al. (Zhang et al. 2023)	Storage	The redundant data storage in the grain-and-oil-food-supply chain	IoT devices, MySQL database, machine learning, and IPFS	A blockchain-based traceability model for the grain-and-oil-food-supply chain	Enabling multi-source data uploading, lightweight storage, and data recovery

Zou et al. (Zou et al. 2023)	Storage	Incorporating the large volume and spatiotemporal characteristics of remote sensing data	IPFS	A remote sensing data storage model based on a multi-chain structure blockchain architecture	Data sharing and management
Lin et al. (Lin et al. 2017)	Storage	Agricultural data security and monitoring data sharing	ICT-based system	A model ICT e-agriculture system with a blockchain infrastructure	Data Integrity and sharing: Immutability and decentralization (instead of a centralized database)
Pranto et al. (Pranto et al. 2021)	Storage	Agricultural data sharing and monitoring	Smart contracts and IoT devices	A blockchain-based IoT and smart contracts	Data Integrity and sharing: Immutability, data availability, and transparency
Omar et al. (Omar et al. 2023)	Stock/ Crop Insurance	Complexity, excessive costs, and a lack of trust in conventional crop insurance methods	IPFS and Ethereum Smart contracts	Blockchain-based crop index insurance solution using Ethereum smart contract	Immutability and Transparency throughout the insurance ecosystem
Iyer et al. (Iyer et al. 2021)	Stock/ Crop Insurance	Farmers' risk vulnerability due to insurance gaps, private sector absence, crop security, and the need for innovative insurance products	Know Your Customer (KYC) verification and smart contract	A decentralized peer-to-peer crop insurance framework	Agricultural Insurance: Promotes trust in an untrusted environment by providing data integrity – The system enables the provision of insurance coverage for nonseasonal and unusually heavy rainfall.
Jha et al. (Jha et al. 2021)	Stock/ Crop Insurance	Cost of administering insurance and the great losses due to natural disasters	Smart contracts and a cloud environment	A blockchain based affordable crop insurance solution	Agricultural Insurance: Infrastructure for storing, validating and transfer of data securely
Vos et al. (Vos et al. 2017)	Stock/ Land Registration	Fraud, corruption, and lack of trust in classical land registration systems	Smart contracts	A comparison between a classical land registration and blockchain-based land registration system for good governance	Agricultural registration and record keeping: Ownership authentication, enhance trust, and reduce cost by eliminating intermediaries
Cho and Lee (Cho and Lee 2019)	Stock/ Animal Registration	Authenticate animals as specific preregistered entities in various contexts	Nose-print recognition	Nose-print based animal management system for animal registration and authentication	Authentication: Data integrity and accessibility
Mujeye et al. (Mujeye et al. 2023)	Stock/ Farm Overseeing	Failing to meet the quality of service (QoS)	5G and IoT sensors	Local 5G (L5G) network	Data sharing
Lin et al. (Lin et al. 2017)	Stock/ Farm Overseeing	Data security and monitoring data sharing	ICT-based system	A model ICT e-agriculture system with a blockchain infrastructure for water distribution monitoring	Data Integrity and sharing: Verify data integrity
Patil et al. (Patil et al. 2018)	Stock/ Farm Overseeing	Data sharing, irregular satellite monitoring, expensive security methods for energy consumption, and security in IoT	IoT devices	A lightweight blockchain based framework for smart greenhouse farming	Data Integrity and sharing: Data transparency, immutability, scalability, anonymity, distribution, and decentralization
Descovi et al. (Descovi et al. 2021)	Stock/ Monitoring/ Free Range	Exploring the application of blockchain in the health certification process for birds, and traceability of animal sanitary records	N/A	The integration of an animal sanitary control platform (PDSA-RS) with a private blockchain	Data integrity: Simplifying the animal sanitary control of breeding birds, traceability, immutability, transparency, anonymity, and auditability

Table 1 presents a range of blockchain applications within the context of smart agriculture, that address diverse problems, as outlined in the existing literature. The prevailing focus in many smart agriculture studies, as shown in table 1, revolves around data, particularly data integrity and its correlation with quality management standards and certifications. Various projects within the field require data integrity. Moreover, some projects employed secure data sharing underscoring the significance of data integrity as the primary challenge. In this regard, utilizing blockchain technology can potentially address these problems. For instance, a recent integration of blockchain technology within an IoT-based crop prediction system has ensured secure, tamper-resistant storage of sensor data and crop forecasts. This integration utilizes cryptographic techniques to enhance data integrity, decentralize data management, and establish trust among stakeholders (Sizan et al. 2023).

Blockchain's distributed nature ensures high availability, and its consensus algorithms provide immutability of records. Consequently, in literature, many blockchain applications leverage the integrity property of blockchain to provide services such as auditing insurance, bookkeeping, and secure data storage. These services are closely related to quality management, standardization, and certification purposes. There is also a common use in the market for blockchain technology, particularly when high availability is essential. This makes it a versatile tool within the field of smart agriculture.

In a distributed environment, blockchain can play a crucial role in maintaining data through its high availability and integrity verification. It can either serve as the primary repository for data or support any existing information services by ensuring the integrity of the stored data. Additionally, blockchain systems commonly integrate with IoT devices and systems, which generate data that can be automatically recorded in the blockchain. Through the application of blockchain, the integrity of data can be guaranteed, facilitating the automation of day-to-day monitoring operations in smart agriculture. For example, a study aimed at monitoring the impact of fertilizers on agricultural land and related parameters, such as increased temperature, reduced moisture, and light intensities, by recording data in a system using IoT sensors (Rehman et al. 2023).

Effective bookkeeping also plays a significant role in tracking land and animal information. In turn, this aids insurance systems and facilitates insurance audits, serving audit purposes. This process enhances the monitoring standards and certifications of insurance providers. Given the overarching emphasis on data integrity, blockchain technology has become widely adopted for verifying and ensuring the integrity of data across various applications.

Furthermore, it is noteworthy that blockchain is often employed in conjunction with IoT devices and systems to address different problems, automate non-traditional approaches, and devise innovative automated solutions. Many of the data management practices in smart agriculture involve information services, where data is stored in databases and accessible for querying. Blockchain can serve as the underlying database for such information services, and it can be employed to check if the information contained therein is still valid.

While the utilization of smart contracts in smart agriculture remains limited, they have found particular use in insurance and can also be applied to sales within the market. For instance, blockchain-based crop index insurance has been introduced as an innovative solution to overcome the complexities, high costs, and trust issues that plague traditional crop insurance methods. By utilizing blockchain technology, the solution ensures transparency, as every transaction and data exchange is recorded on an immutable ledger. Smart contracts enable autonomous claims processing, significantly reducing the risk of fraud and expediting payouts to farmers. This system also reduces administrative costs by eliminating intermediaries and streamlining processes, making crop insurance more affordable and accessible, especially for farmers in low-income regions (Omar et al. 2023).

Table 1 highlights different areas in agriculture where blockchain technology is applied to address various research problems and improve the overall agricultural processes. In the literature, studies regarding using blockchain in agriculture are divided into three main categories: production, storage, and stock. Blockchain is used in product supply chain as a solution to enhance its functionality, usage, and credibility. It also focuses on improving grain quality management throughout the transportation chain by leveraging blockchain technology and using the GEBN to enhance efficiency and resilience. Blockchain also addresses security concerns in supply chain information exchange and ensures data integrity and authentication, mitigating risks in the agricultural domain.

Studies in product traceability discuss food safety (Chatterjee et al. 2023; Tian 2016; Kumar and Iyengar 2017; Leng et al. 2018; Lin et al. 2018; Lin et al. 2019; Lucena et al. 2018; Mandela et al. 2023; Saberi et al. 2019; Snyder et al. 2017; Tse et al. 2017) and traceability (Ferrández-Pastor et al. 2022; Sezer et al. 2022); Caro et al. 2018; Tian 2016; Figorilli et al. 2018; Kumar and Iyengar 2017; Lin et al. 2018; Lin et al. 2019; Tse et al. 2017) in the agricultural domain. It addresses the problems of tampering with food data (Chatterjee et al. 2023; Mandela et al. 2023); Tian, 2016; Lin et al. 2018; Lin et al. 2019; Lucena et al. 2018) and the limitations of existing traceability systems (Caro et al. 2018; Leng et al. 2018; Tse et al. 2017). The studies also highlight concerns regarding food safety (Chatterjee et al. 2023; Mandela et al. 2023; Tian 2016; Kumar and Iyengar 2017; Leng et al. 2018; Lin et al. 2018; Lin et al. 2019; Lucena et al. 2018; Saberi et al. 2019; Tse et al. 2017) and emphasize that current food safety systems are inadequate to meet the required standards. Blockchain technology is proposed as a solution to enhance traceability in food supply chain, thereby improving food safety and consumer confidence.

Storing agricultural data is also a pressing concern in smart agriculture. The studies focus on some key challenges in the agricultural sector. For example, they address the difficulty of securely storing agricultural and environmental monitoring data (Zhang et al. 2023; Zou et al. 2023; Lin et al. 2017; Pranto et al. 2021; Xie et al. 2017). They also emphasize the movement of vital data (Lin et al. 2017; Pranto et al. 2021; Xie et al. 2017; Zhang et al. 2023; Zou et al. 2023) within the agricultural system. To overcome these challenges, studies (Zhang et al. 2023; Zou et al. 2023; Lin et al. 2017; Pranto et al. 2021; Xie et al. 2017) leverage using blockchain technology that offers a secure and decentralized solution for data storage and management, ensuring the availability and integrity of vital agricultural information.

The literature focuses on improving crop insurance using blockchain technology. Studies (Omar et al. 2023; Bai et al. 2022; Iyer et al. 2021; Jha et al. 2021) in this domain present some approaches such as a decentralized peer-to-peer crop insurance framework (Iyer et al. 2021) to protect farmers' interests and facilitate secure contracts with investors, and a decentralized platform with smart contracts (Jha et al. 2021) to detect fraud and coordinate insurers and farmers efficiently. Blockchain and IoT-based framework was also used in (Bai et al. 2022) to enhance insurance processing, security, and settlement by eliminating human interaction.

This paper covers two main topics in stock registration. Firstly, it discusses the potential applications of blockchain technology in land registration and administration (Anand et al. 2017; Barbieri and Gassen 2017; Vos et al. 2017), highlighting its advantages as well as addressing some concerns about the complexity of integrating it in existing land registry systems. Secondly, the paper presents an animal administration system research that utilizes blockchain for animal identification using nose-print recognition (Cho and Lee 2019), allowing for secure identification, and tracking of animals in various areas such as animal hospitals, pet stores, shelters, and pet insurance.

Blockchain can serve as a useful tool in farm overseeing. For example, Lin et al. (Lin et al. 2017) proposed an e-agriculture system model that utilizes ICT and blockchain for water distribution monitoring. Water quality data is added to the blockchain, ensuring its integrity and availability across all nodes. IoT devices can also be employed as a centrally managed blockchain, providing a more secure and efficient system for remote greenhouse monitoring and automation.

The literature includes some studies related to the application of blockchain technology in monitoring livestock grazing and free range. The AppliFarm platform (ADM 2023) enables digital evidence for animal welfare and livestock grazing through linked tags to track their grazing areas and ensure high-quality grazing for the livestock. Another case study on blockchain's application in the health certification of poultry farms was presented, demonstrating the simplification of animal sanitary control for breeding birds and data storage in the blockchain.

Blockchain technology in smart agriculture faces several technical challenges that need to be addressed to enable its broader adoption. One of the key issues is scalability. As the number of connected IoT devices increases, blockchain networks may struggle to handle the large volume of transactions generated by these devices, which can lead to slower processing times and higher operational costs. To address scalability and energy consumption challenges, alternative consensus mechanisms like Proof of Stake (PoS), used by Ethereum 2.0 and Cardano, provide energy efficiency while maintaining robust security. Additionally, Delegated Proof of Stake (DPoS), employed by platforms such as EOS and Tron, further improves scalability but comes with the trade-off of increased centralization (Alkhodair et al. 2023).

Another significant challenge is data privacy. Public blockchain platforms are transparent by design, which could expose sensitive agricultural data to unauthorized parties. To overcome this, permissioned blockchains can be implemented to restrict access, ensuring that only authorized participants can access certain data. Furthermore, techniques like Zero-Knowledge Proofs (ZKPs) (Zhang et al. 2023) can allow data to be verified without revealing the underlying information, ensuring privacy while maintaining transparency.

Another major limitation is the absence of standardized regulations and international frameworks, which restrict interoperability and delay widespread implementation. Connectivity issues in rural areas further complicate participation, as blockchain networks require reliable internet access. Additionally, the technology demands substantial IoT infrastructure to ensure accurate and trustworthy data input, creating logistical and financial hurdles. Uncertainty regarding the legal interpretation of smart contracts and governance frameworks adds to the complexity, posing legal and operational risks. Overcoming these regulatory, infrastructural, and accessibility challenges is essential for blockchain to achieve its transformative potential in enhancing transparency, efficiency, and sustainability in the agricultural sector (AGDAILY 2024).

Different blockchain systems may use incompatible data formats or communication protocols, making it difficult to integrate them with existing agricultural systems and it can arise communication issues. The development of universal standards for data exchange and protocol integration would facilitate smoother interoperability and greater collaboration across platforms, leading to more efficient blockchain-based solutions in agriculture. Addressing these technical limitations will be crucial in unlocking the full potential of blockchain to improve transparency, efficiency, and security in the agriculture sector.

Although there are significant studies have examined various aspects of smart agriculture, researchers are increasingly directing their focus toward the supply chain (Ahamed and Vignesh 2022; Ashfaq 2022; Chatterjee et al. 2023; Haji et al. 2022; Kumar and Dwivedi 2023; Mandela et al. 2023), encompassing the entirety of activities from crop cultivation to consumer. This shift is occurring because individuals are increasingly recognizing the importance of effectively managing this process to ensure that farming operations are conducted efficiently and with traceability. Delving into the supply chain, researchers aim to identify strategies for resource optimization, product enhancement, and waste reduction in agricultural operations. Additionally, the increasing consumer consciousness regarding food provenance and production methods underscores the need to ensure transparency within the supply chain. Technologies like blockchain help achieve this goal by enabling the enhanced tracking of food origins and the handling processes. Consequently, the exploration of the relationship between smart agriculture and the supply chain is emerging as a significant area of research, which will yield substantial improvements in agricultural practices for broader societal benefit.

Despite the numerous benefits of using blockchain in smart agriculture, there are still several open questions and areas that require further research. For instance, using blockchain to track soil quality metrics such as nutrient levels, pH, and organic matter content. This data could then be used to optimize soil health and productivity and identify areas requiring specific treatments. In smart agriculture, Blockchain technology can enable several transformative capabilities. For example, the creation of decentralized markets, and fostering direct connections between farmers and buyers. Additionally, blockchain can facilitate the development of auditing systems to monitor and support environmentally friendly farming practices. By utilizing smart contracts, the use of intermediaries can be minimized, which will lead to reduced food prices and improved efficiency in the agricultural supply chain. Finally, blockchain could be used to track research data, funding, and collaborations in agricultural research, enabling greater sharing and collaboration among researchers.

Feature studies on blockchain applications in agriculture should focus on several emerging areas. Developing standardized frameworks is essential to enable seamless integration of blockchain with IoT and AI technologies, fostering interoperability across industries. Studies are needed to assess the economic and operational viability of blockchain solutions, particularly in resource-constrained farming environments. Exploring hybrid blockchain models that combine public and private chains could help achieve a balance between transparency and scalability. Furthermore, addressing ethical considerations and socio-economic impacts is critical to ensure equitable benefits for smallholder farmers and reduce potential disparities. Finally, localized investigations should examine how blockchain can address region-specific challenges, such as enhancing drought resilience in arid regions or implementing disease tracking systems in livestock farming, tailoring solutions to the unique needs of different agricultural contexts.

In conclusion, this paper has highlighted the numerous applications of blockchain technology in smart agriculture, including product supply chain management, storage, farm, and stock management. By leveraging the power of blockchain, we can create a more transparent, sustainable, and equitable food system for all. However, further research is required to address open questions and areas to ensure the successful integration of blockchain into the agriculture industry. Overall, this paper contributes to the ongoing discussion on the potential of blockchain in smart agriculture and highlights the need for further research to realize its full potential.

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Disclaimer: The entirety of the ideas and contributions presented are the authors' original work. Nonetheless, we incorporated a Large Language Model (LLM) to improve the clarity and readability of the text. It should be noted that despite utilizing the LLM for language enhancement, the work remains solely our own.

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