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Determination of combining ability, heterosis, hetorobeltiosis and dominance gene effect in inbred popcorn (*Zea mays* everta Sturt.) lines*

Erkan ÖZATA[1]*, Bilal UÇAR[2]

[1]Black Sea Agricultural Research Institute, Samsun, Türkiye
[2]Seed Certification and Variety Test Station, Ministry of Agriculture and Forestry, Samsun, Türkiye

***Corresponding author e-mail:** erkan.ozata@tarimorman.gov.tr

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Abstract: This study aimed to determine the effects of heterosis, heterobeltiosis and dominance on the inheritance of agronomic traits in popcorn. The study was carried out for two years (2018-2019) under ecological conditions of Samsun province. A total of 32 inbred popcorn lines were crossed with two tester lines (i.e., 'P206' and 'HP7211') during 1st year and 64 hybrids were obtained. Yield trial was carried out according to the 8 × 8 partially balanced Lattice trial design with 2 replications during 2nd year. Yield and yield components of each genotype were determined, hybrid vigor of the hybrids and general combaning abilities of the parents were examined. Heterosis, heterobeltiosis, and general combaning abilities occurred positively and negatively in all traits. Heterosis rates for grain yield trait were between -11.33 and 178.05%, whereas heterosis rates for bursting volume trait were between -0.9 and 69.9%. Heterobeltiosis rates ranged between -15.85 and 163.86% for grain yield and -14.4 and 69.1% for bursting volume. Overdominance and partial dominance genes were effective in the inheritance of the examined traits. It was also determined that 'TCK129', 'TCK 135', 'TCK136' and 'TCK144' lines can be used as genitor lines due to their high grain yield and average bursting volume. These results indicate that new commercial popcorn hybrids which can be planted in Türkiye can be developed in a short time.

Keywords: Popcorn, GCA, heterosis, heterobeltiosis, dominance effect

Kendilenmiş cin mısır (*Zea mays* everta Sturt.) hatlarında birleştirme yeteneği, heterosis, hetorobeltiosis ve dominans gen etkinliğinin belirlenmesi

Öz: Bu çalışmada, patlamış mısırın agronomik özelliklerinin kalıtımında heterosis, heterobeltiosis ve baskınlığın etkilerinin belirlenmesi amaçlanmıştır. Çalışma, Samsun ekolojik koşullarında iki yıl (2018-2019) süreyle yürütülmüştür. Çalışmanın birinci yılında 32 adet kendilenmiş patlamış mısır hattı, iki test hattı ('P206' ve 'HP7211') ile melezlenmiş ve 64 adet melez elde edilmiştir. İkinci yılda ise verim denemesi, 8 × 8 kısmi dengeli Latis deneme desenine göre 2 tekrarlamalı olarak yürütülmüştür. Denemede her genotipe ait verim ve verim öğeleri belirlenmiş, melezlerin melez gücü ve ebeveynlerin genel kombinasyon uyumları incelenmiştir. Heterosis, heterobeltiosis, genel kombinasyon uyumları tüm özelliklerde olumlu ve olumsuz yönde ortaya çıkmıştır. Denemede tane verimi özelliğinde heterozis oranları-%11.33 ile %178.05 aralığında, patlama hacmi özelliğinde heterozis oranları-%0.9 ile %69.9 aralığında belirlenmiştir. Heterobeltiosis oranları tane verimi özelliğinde-%15.85 ile %163.86 aralığında, patlama hacmi özelliğinde ise-%14.4 ile %69.1 aralığında ölçülmüştür. Çalışmada incelenen özelliklerin kalıtımınında, aşırı baskınlık ve kısmi baskınlık genlerinin etkili olduğu belirlenmiştir. Ayrıca yüksek tane verimi ve ortalama patlama hacmi kapasiteleri nedeniyle 'TCK129', 'TCK 135', 'TCK136' ve 'TCK144' hatlarının genitor hatları olarak kullanılabileceği belirlenmiştir. Bu sonuçlar kısa sürede Türkiye'de ekilebilecek yeni ticari patlamış mısır melezlerinin elde edilebileceğini göstermektedir.

Anahtar kelimeler: Cin mısır, GCA, heterosis, heterobeltiosis, dominans etkisi

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1. Introduction

Popcorn (*Zea mays* everta Sturt.) can be easily popped using popping methods (oil, air and microwave), and it is regarded as one of the most consumed snacks from past to present. Being a high-quality and concentrated food source with high fiber, protein, antioxidant and vitamin content has allowed it to take its place in breakfasts and meals. It is estimated that the popcorn market will increase from 5.5 billion US$ to 13.5 billion US$ in the next decade (Özata et al., 2024). Türkiye is ranked among the top ten countries in the world in terms of popcorn production (50-60 thousand tons) and export (25-30 thousand tons). Türkiye has the potential to rise to the top in the popcorn market with improvements in yield and quality.

Popping volume (PV), nonpopped grain ratio (NPGR), grain weight and size are controlled by many genes in popcorn breeding since they are quantitative characters. Although this situation creates some difficulties in breeding studies, the popping volume has been doubled and the nonpopped grain ratio (NPGR) has been reduced by 75% in the last 50 years (Sweley, 2013). The main goal in popcorn breeding is to develop varieties with high PV and low NPGR, stable, uniform, and fast grain moisture loss (Rinaldi et al., 2007; Dhliwayo, 2008; Effa et al., 2011; Freitas Júnıor et al., 2009). The breeder must have sufficient knowledge about the inheritance and nature of the gene action of yield and the yield-related traits in order to implement a successful breeding strategy (Alhadi et al., 2013). The ability of an improved inbred line to transfer the desired performance to its hybrid progeny is defined as the combining ability. The combining ability of parents provides information about the genetic structure, as well as gene action that plays a role in the inheritance of quantitative traits (Begum et al., 2018; Gosai et al., 2017). The basis of hybrid breeding varies according to hybrid vigour. The superior performance of a hybrid over the average of two parental strains is defined as heterosis (He), and the superior performance of a superior parent is defined as heterobeltiosis (Hb).

There are two views on the genetic control and inheritance of major agronomic traits in popcorn. The first view is that the control of PV is due to additive genes only, while the control of grain yield (GY) is primarily due to dominance genes (Larish and Brewbaker 1999; Pereira and Amaral Júnior, 2001; Freitas Júnior et al. 2006; Rangel et al. 2011; Cabral et al. 2016). The second view is that dominance genes may also effective to some extent on PV in parallel with GY. The effectiveness of dominant genes in both traits (GY and PV) enables the transfer of desirable characteristics to hybrids by maximizing the benefits of high heterosis. (Babo et al. 2006; Li et al. 2007; Freitas, et al. 2014; Coan et al. 2019; Santos et al. 2020; Guimarães et al. 2019). Although studies on the genetic gain of He, Hb, and dominance effects in the inheritance of agricultural traits of popcorn exist worldwide, no research has been found in Türkiye. Understanding genetic gains in the development of hybrids with high PV and GY is crucial for breeding studies. The assessment of potential genetic gains in popcorn, along with the analysis of genetic parameters and the investigation of heterotic and dominance effects on the genetic control of key agricultural traits, is of great importance for the reasons mentioned above. This study aimed to determine the effects of He, Hb and dominance on the inheritance of agronomic traits of popcorn.

2. Materials and Methods

2.1. Experimental site

A total of 32 inbred popcorn lines and 2 tester ('HP7211' and 'P206') lines were used in the study. The tester lines had high combination ability developed in the Batı Akdeniz Agricultural Research Institute (BAARI) popcorn breeding research. In 2018, two tester lines ('P206' and 'HP7211') and 32 popcorn inbred lines were crossed under controlled conditions and 64 popcorn hybrids were produced. The popcorn inbred lines were developed from materials obtained from different genetic sources (domestic and foreign populations and F2) between 2013 and 2018. For the construction of the test hybrid, S6 inbred lines were planted as the main parent in two different isolated areas (without corn production adjacent or at least 500 m away) and the popcorn inbred lines used as fathers (testers) were planted in the adjacent rows. The number of mother and father rows were 4 and 2, respectively. The experiment was conducted in 2019 at the Bafra trial station according to the partially balanced Lattice trial design (8 × 8) with 2 replications. Morphological and physical traits were observed in accordance with the technical instructions for agricultural value measurement experiments (TTÖDTK, 2018). Planting was done with a disc type pneumatic seeder with 70 cm row spacing and 20 cm plant spacing. Fertilizers were applied as 80 kg/ha phosphate P_2O_5 and 180 kg/ha N (nitrogen).

All cultural practices (irrigation, fertilization, hoeing, spraying, etc.) were performed as recommended. Data relating to days to start flowering, thousand grain weight, yield per hectare, popping volume, and non-popping grain rate were recorded. Thousand grain weight, grain moisture and flowering were made according to TDÖDTT (2018), while the popping volume and non-popping grain rate (%) were made according to Sweley (2013). Popping was done with 1100 W Kiwi KPM-7408 brand hot air blowing machines in the 11.8-12.5% moisture range. The data of each observed trait were analyzed by analysis of variance (ANOVA). Estimation of heterosis, potence ratio, and general combining ability were carried out as follows. Heterosis, heterobeltiosis and dominance effect determination heterosis (H1) and heterobeltiosis (H2) were calculated with the following formula (Mather and Jinks, 1971).

a) $H1\ (\%) = (F1\text{-}MP/MP) \times 100$,

Where F1= mean value of the hybrid population; MP = mean of parent)

b) $H2\ (\%) = (F1\text{-}BP/BP) \times 100$,

Where F1= mean value of the hybrid population; BP = better-parent

Potency ratio (D.E.) was calculated using the following formula suggested by Mather (1949) and Smith (1952).

c) $D.E. = (F1 - MP)/(0.5 \times P2 - P1)$,

Where F1= mean value of the hybrid population; MP = middle parent; P2= mean of highest parent; P1= mean of lowest parent. When D.E. = +1, it signifies complete dominance; when D.E. falls between -1 and +1, it indicates partial dominance; D.E. = 0 represents no dominance. If D.E. exceeds ±1, overdominance is observed. The '+' and '−' indicate the direction of dominance of one of the parents.

3. Results and Discussion

3.1. General combining ability (GCA)

Significant differences were determined among the hybrids in all traits ($p<0.01$). General combining ability (GCA), heterosis, heterobeltiosis and dominance effect (DE) estimations indicated that the genetic difference between the hybrids created sufficient variation. These results show that the parents are sufficiently different from each other and provide various allelic combinations. The average grain yield of the hybrids was 3.71 tonnes/ha, days to start flowering were 88 days, grain moisture was 20.1%, popping volume (PV) was 28.5 g/cm^3, non-popping grain rate (NPGR) was 14.1%, and 1000 grain weight (TGW) was 139.1 g. The GCA showed grain yield ranging from -16.49 to 27.53 tonnes/ha, flowering ranging from -7.88 to 2.4 days, grain moisture -3.78 to 2.53%, PV ranging from -8.2 to 9.04 g/cm^3, NPGR ranging from -2.84 to 3.7%, and TGW ranging from -29.54 to 31.97 g. The highest GCA in grain yield was determined from 'TCK152' × 'P206', the earliest flowering time from 'TCK122' × 'HP7211', the lowest grain moisture from 'TCK129' × 'P206'. The highest PV was noted for 'TCK125' × 'P206', the lowest NPGR was recorded for 'TCK137' × 'HP7211', and the highest TGW was observed for 'TCK141' × 'P206' (Table 1). Considering the traits examined in GCA, popcorn inbred lines showed different combining ability with both tester inbred lines. The highest grain yield combining ability was recorded for 'HP7211' tester line (Figure 1). The GCA effects were obtained in both directions (positive and negative) in terms of grain yield and PV, which are important selection criteria in popcorn. Among hybrids, 14 combinations in grain yield, 33 combinations in flowering, 1 combination in grain moisture, 29 combinations in PV, 4 combinations in NPGR, and 37 combinations in TGW showed positive comninig ability. The selection of superior genotypes that will meet the needs of the producer and consumer in popcorn is quite difficult since PV and grain yield are quantitative traits. The dominance of the negative relationship between both traits restricts simultaneous selection (Kamphorst et al., 2021; dos Santos Junior, et al., 2023). An inverse relationship between grain yield and PV in terms of GCA was noted in the current study. These results are consistent with dos Santos Junior et al. (2023), Santos et al. (2017), and Mafra et al. (2018). In addition, when grain yield and PV were evaluated together in terms of GCA, 'TCK 132' inbred line showed positive combination compatibility with both testers ('P206' and 'HP7211'). Similarly, 'TCK135', 'TCK136' and 'TCK 144' popcorn inbred lines showed positive combination ability with 'HP7211' tester line. The 'TCK 138' popcorn line had positive combination ability with 'P206' tester line. These popcorns inbred lines have high potential to be used in breeding programs aiming to obtain simultaneous gains in the future.

3.2. Heterosis

Significant differences were observed in the heterosis rates of the hybrids included in the study. The main purpose of using the check hybrid is to select the best parents in terms of certain traits for hybrid breeding. Heterosis values also varied according to the testers (Figure 2). The highest heterosis values in grain yield were determined for 'HP7211' tester, and for 'P206' tester in other traits. Positive and negative heterosis was measured in all parameters included in the study. However, almost all the hybrids examined in grain yield and PV showed positive heterosis. Our findings are similar to those of Ghosh et al. (2018) in popcorn and Flint-Garcia et al. (2009) reported that heterosis values changed positively and negatively according to the traits examined in their studies on grain maize. However, these results suggest that performing each trait in its biological context will contribute to obtaining maximum heterosis in solving the heterosis mechanism. In our study, heterosis rates varied between-11.33 and 178.05% in grain yield, -3 and 9.1% in flowering, -23.1 and 6.6% in grain moisture, and -0.9 and 69.9% in PV (Table 2). The results of our study are generally similar to the results of Kumar et al. (2023), Soni and Khanorkar (2013), Guimaraes et al. (2007), Amanullah et al. (2011) and Kumar et al. (2013). Guerrero et al. (2014) stated that in maize breeding, a heterosis level of at least 20% is desirable for effective utilization in crosses. Approximately 90% of the grain yield heterosis rates and 75% of the PV rates of the crosses were above the desired heterosis rates in maize breeding. It is thought that this difference is due to the genetic structure of the parents and environmental differences and the differences used in data analysis. Guillén-de la Cruz et al. (2009) found that as the genetic diversity of parent lines increases, the variation among their crosses also increases in both agronomic and physiological traits. As the genetic difference between inbred lines increases, the heterosis rate also increases. Using this approach, inbred lines and testers provide information about which heterotic group the inbred lines belong to. Lines that show good combination ability with the tester are thought to belong to a different heterotic group. Inbred lines 'TCK 158', 'TCK138' and 'TCK 136' had high heterosis rates for grain yield and PV with both tester groups. There are no heterotic groups defined differently from grain corn in popcorn breeding. It is thought that lines that show positive and high combining ability with both testers are from a different heterotic group.

3.3 Heterobeltiosis

Significant differences were recorded between the heterobeltiosis rates of grain yield and yield traits of the hybrids included in the study. It was determined that heterobeltiosis rates varied between-15.85 and 163.86% in grain yield, -3.6 and 8.4% in flowering, -25.7 and 3% in grain moisture, -1.4 and 69.1% in PV, -44.63 and -2.12% in NPGR, and -19.02 and 26.39% in 1000-grain weight (Table 3). The heterobeltiosis rates were lower than the heterosis rates. Utilization of heterosis or heterobeltiosis can speed up the process of generating superior hybrids. Heterosis, or hybrid vigour, is the superiority of the hybrid for a certain trait over the mean of the parents, whereas heterobeltiosis is a form of heterosis where the hybrid is superior to its best performing parent (Beche et al. 2013) Jones (1957) defined heterosis as the expression of dominance deviation, a variance from mid parent value, which may be explained by the additive effects of several desired dominant alleles, or as "overdominance," the combined effect of (two) different alleles at the same gene locus, or a combination of both. It is expected that the heterobeltiosis rate is lower than the heterosis rates in the examined traits. Positive and negative heterobeltiosis values were determined in terms of the traits examined in hybrid combinations. The highest heterobeltiosis value was obtained from grain yield. When grain yield, popping volume and flowering time traits were evaluated together, it was determined that almost all the combinations had positive heterobeltiosis values.

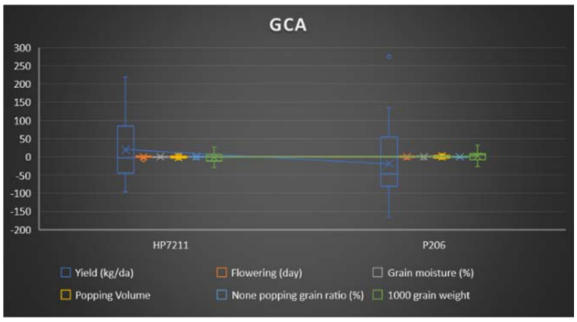

Figure 1. General combination ability of popcorn genotypes according to tester lines.

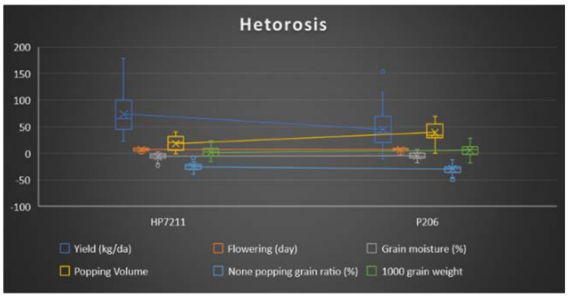

Figure 2. Heterosis value comparisons of popcorn genotypes according to tester lines.

Our findings are similar and different from previous studies (Soni and Khanorkar 2013; Kumar et al. 2023; Kumar et al. 2014). The determined differences are due to the genetic structure of the parents and environmental differences and the genetic differences of the corn types used. The 'TCK 158', 'TCK138' and 'TCK 136' inbred lines gave high heterobeltiosis rates similar to heterosis rates in grain yield and popping volume with both tester groups (Figure 3). From the definitions, heterobeltiosis helps a breeder to make more stringent selections than heterosis, as also reported by Lamkey & Edwards (1999). The obtained results are similar to Begum et al. (2017) and Khan et al. (2019) and Kumar et al., (2023).

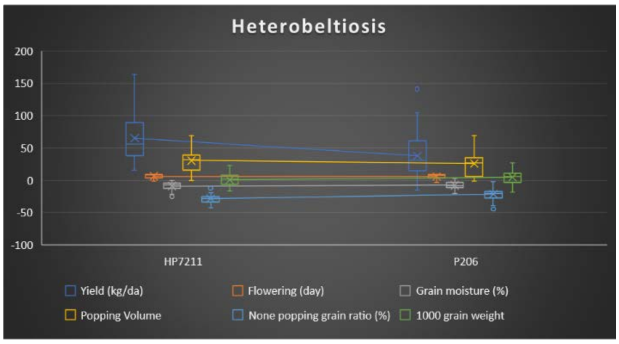

Figure 3. Heterobeltiosis value comparisons of popcorn genotypes according to tester lines.

3.4. Dominance effect

The dominance effect caused differences in the examined traits of the hybrids included in the experiment. The dominance effect was between-11.65 and 23.57% in grain yield, and it was >±1 in 59 combinations and between ±1 in 4 combinations. Positive complete and intense dominance was determined in the hybrids. Since the potency ratio was >1 in most of the combinations in the study, it suggests that the inheritance in grain yield is only due to overdominance. Our results are consistent with the studies reporting that overdominance is effective in grain yield in maize (Ghosh et al., 2018, Alhadi et al., 2013, Srdić et al., 2008).

The dominance effect of the flowering ranged between-15.38 and 4.80%, and it was determined to be >±1 in 59 hybrids and between ±1 in 5 hybrids (Table 4). Our findings revealed that intense and complete dominant genes are effective in the inheritance of flowering time. Indeed, our findings are similar to the results of El-Badawy (2012) and Ghost et al., (2018), who reported that complete dominance is effective in flowering. Grain moisture dominance effect varied between -5.28 and 3.39%, and it was determined that it was > ±1 in 48 hybrids, between ±1 in 16 hybrids and that excessive, complete and ineffective genes were effective, respectively. Both dominance situations show that dominant and partial dominance effects are intense in grain moisture. The obtained results are similar to the results of Begum et al. (2017), Rahman et al., (2019) and Kumar et al., (2023). Popping volume dominance effect was between-14.91 and 16.43%, and it was determined that it was > ±1 in 58 combinations and between ±1 in 6 hybrids. It was determined that in most hybrids, overdominance and partial dominance genes were effective in terms of PV. Dong et al. (2007) reported that partial dominance and overdominance were effective on popping volume inheritance. Lima et al. (2019), Oliveira et al. (2019), Santos et al. (2020) and Santos Junior et al. (2023) stated that dominance effects had a greater effect on PV inheritance. The results obtained are in accordance with the above-mentioned studies. The NPGR varied between-5.15 and 6.73%, and the NPGR dominance effect was determined to be > ±1 in 34 hybrids and ±1 in 30 hybrids. Overdominance was determined in half of the combinations, and partial dominance was determined in the other half. The results obtained from our study are similar to the results of Mosa et al. (2024). The dominance effect in 1000-grain weight varied between-24.62 and 26.64% and was determined to be > ±1 in DE 63 combinations and between ±1 in 1 hybrid. It was determined that overdominance and partial dominance were effective on 1000 grain weight. The results obtained in our study are consistent with Cabral et al. (2016) and Kumar et al. (2021). In addition, it was determined that, similar to heterosis and heterobeltiosis rates, dominance effect also differed from the tester lines (Figure 4). The fact that overdominance and partial dominance conditions differed in testers suggests that they contain different heterotic groups due to their genetic structures.

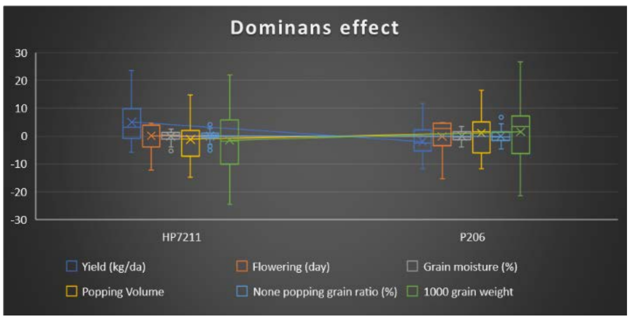

Figure 4. Dominance effect rates comparisons of popcorn genotypes with according to tester lines.

Table 1. General combination ability of traits examined in popcorn.

Female Line	×	Tester Line	Yield (tonnes/ha)		Flowering (day)		Grain moisture (%)		Popping Volume (%)		None popping grain ratio (%)		1000 grain weight (g)	
TCK120	×	HP7211	2.398	n.s.	2.12	*	0.23	n.s	1.10	**	0.51	n.s	6.75	**
TCK120	×	P206	-6.474	*	2.12	*	2.13	n.s	0.90	*	2.41	*	14.81	**
TCK121	×	HP7211	-3.478	n.s	2.12	*	-0.43	n.s	-1.34	**	0.39	n.s	26.32	**
TCK121	×	P206	1.556	n.s.	2.12	*	-1.03	n.s	2.17	**	-0.01	n.s	9.01	**
TCK122	×	HP7211	3.393	n.s.	-7.88	**	2.53	*	-4.32	**	-0.27	n.s	21.65	**
TCK122	×	P206	-12.286	**	2.12	*	-1.93	n.s	-1.64	**	0.96	n.s	-2.19	**
TCK123	×	HP7211	-4.404	n.s.	2.12	*	-2.88	*	0.69	n.s	-0.12	n.s	-6.29	**
TCK123	×	P206	-12.829	**	2.12	*	1.03	n.s	8.09	**	-0.21	n.s	4.56	**
TCK124	×	HP7211	0.961	n.s.	2.12	*	-1.08	n.s	0.90	**	-0.28	n.s	7.70	**
TCK124	×	P206	-0.5992	n.s	1.12	n.s	1.93	n.s	8.23	**	-0.92	n.s	17.06	**
TCK125	×	HP7211	-2.548	n.s.	2.12	*	-0.18	n.s	-1.13	**	0.18	n.s	2.65	**
TCK125	×	P206	-6.177	n.s	-3.88	**	-0.58	n.s	9.04	**	-0.41	n.s	-0.05	n.s
TCK126	×	HP7211	-3.569	n.s	-1.88	*	-0.28	n.s	-1.34	**	0.45	n.s	3.20	**
TCK126	×	P206	-3.126	n.s.	-1.88	*	0.28	n.s	4.07	**	-1.71	n.s	10.21	**
TCK127	×	HP7211	-9.267	**	1.12	*	-0.93	n.s	2.67	**	-0.84	n.s	17.29	**
TCK127	×	P206	-16.498	**	-3.88	**	-1.83	n.s	0.90	*	0.60	n.s	5.95	**
TCK128	×	HP7211	-4.969	n.s.	1.12	**	-0.03	n.s	5.19	**	0.11	n.s	4.16	**
TCK128	×	P206	-5.068	n.s	2.12	n.s	-2.33	n.s	2.22	**	-0.44	n.s	12.36	**
TCK129	×	HP7211	-7.323	*	1.12	*	-0.93	n.s	6.04	**	-0.21	n.s	2.27	**
TCK129	×	P206	13.502	**	2.12	n.s	-3.78	**	0.29	n.s	0.12	n.s	6.39	**
TCK130	×	HP7211	-9.618	**	2.12	*	-0.73	n.s	-0.11	n.s	2.29	*	-11.57	**
TCK130	×	P206	-8.701	**	2.12	*	1.38	n.s	8.97	**	-0.64	n.s	-11.92	**
TCK131	×	HP7211	-1.59	n.s.	2.12	*	-0.18	n.s	1.71	**	1.10	n.s	22.16	**
TCK131	×	P206	-8.267	*	2.12	*	-0.33	n.s	4.59	**	-0.05	n.s	1.45	*
TCK132	×	HP7211	16.869	**	-1.88	*	-0.08	n.s	0.95	**	1.56	n.s	-8.63	**
TCK132	×	P206	1.801	n.s.	2.12	*	0.38	n.s	0.90	*	-2.51	**	25.95	**
TCK133	×	HP7211	8.773	*	2.12	*	0.93	n.s	-3.16	**	-1.99	*	-2.79	**
TCK133	×	P206	2.881	n.s	2.12	*	-0.83	n.s	0.90	*	3.70	**	-2.44	**
TCK134	×	HP7211	-4.908	n.s	2.12	*	0.08	n.s	-3.36	**	-0.38	n.s	-29.54	**
TCK134	×	P206	6.658	*	2.12	*	0.78	n.s	-0.31	n.s	0.83	n.s	-25.84	**
TCK135	×	HP7211	16.653	**	-1.88	*	-0.33	n.s	6.61	**	0.56	n.s	-12.29	**
TCK135	×	P206	6.254	n.s	2.12	*	1.68	n.s	-6.21	**	-0.19	n.s	5.58	**
TCK136	×	HP7211	15.426	**	1.12	n.s	1.63	n.s	8.20	**	-2.69	**	-12.29	**
TCK136	×	P206	6.305	n.s	2.12	*	0.38	n.s	-6.51	**	0.20	n.s	-7.05	**
TCK137	×	HP7211	9.471	*	-1.88	*	-0.23	n.s	0.56	*	-2.84	**	-25.86	**
TCK137	×	P206	-5.21	n.s	2.12	*	0.68	n.s	-0.92	**	-1.31	n.s	6.40	**
TCK138	×	HP7211	10.758	*	-3.88	**	1.18	n.s	-1.76	n.s	0.52	n.s	1.48	*
TCK138	×	P206	10.426	**	-3.88	**	0.13	n.s	0.95	**	-0.81	n.s	26.87	**
TCK139	×	HP7211	21.902	**	-0.88	n.s	-0.73	n.s	-5.09	**	0.52	n.s	-16.17	**
TCK139	×	P206	-4.365	n.s	-5.88	**	-0.23	n.s	2.94	**	-1.17	n.s	6.33	**
TCK141	×	HP7211	1.447	n.s.	-4.88	**	-0.18	n.s	-1.88	**	-0.69	n.s	-24.48	**
TCK141	×	P206	-15.134	**	-4.88	**	0.33	n.s	-5.40	**	-1.92	*	31.97	**
TCK143	×	HP7211	4.799	n.s.	-3.88	**	-0.83	n.s	-4.18	**	-0.44	n.s	-18.54	**
TCK143	×	P206	1.018	n.s	-4.88	**	1.28	n.s	0.15	n.s	-1.37	n.s	-10.96	**
TCK144	×	HP7211	13.625	**	-2.88	**	-2.73	*	0.95	**	0.36	n.s	-10.37	**
TCK144	×	P206	12.811	**	2.12	**	0.78	n.s	-4.58	**	-1.37	n.s	-8.66	**
TCK145	×	HP7211	-4.598	n.s.	-1.88	*	-1.13	n.s	-1.47	**	-1.69	n.s	5.46	**
TCK145	×	P206	-13.716	**	-0.38	*	0.98	n.s	1.31	**	-0.07	n.s	-7.36	**
TCK146	×	HP7211	-3.32	n.s.	0.12	n.s	-0.18	n.s	2.52	**	0.86	n.s	8.25	**
TCK146	×	P206	-5.33	n.s	2.12	*	-1.38	n.s	0.64	n.s	-0.41	n.s	-25.82	**
TCK148	×	HP7211	-6.752	*	0.12	n.s.	-1.58	n.s	0.15	n.s	0.63	n.s	-2.55	**
TCK148	×	P206	-0.438	n.s	2.12	*	1.33	n.s	-5.19	**	-0.34	n.s	3.93	**
TCK151	×	HP7211	-1.429	n.s.	0.12	n.s	1.18	n.s	-5.09	**	0.16	n.s	-1.54	*
TCK151	×	P206	-11.683	**	0.12	n.s.	1.93	n.s	-3.29	**	1.03	n.s	3.57	**
TCK152	×	HP7211	2.598	n.s	-4.88	**	0.88	n.s	0.50	n.s	0.60	n.s	-7.18	**
TCK152	×	P206	27.532	**	0.12	n.s	-0.18	n.s	-4.58	**	-0.54	n.s	5.42	**
TCK153	×	HP7211	7.707	*	2.12	*	1.48	n.s	-5.19	**	0.11	n.s	6.91	**
TCK153	×	P206	-4.888	n.s	2.12	*	1.83	n.s	0.94	**	0.82	n.s	-7.63	**
TCK154	×	HP7211	-0.689	n.s.	2.12	*	0.88	n.s	-5.70	**	-0.09	n.s	-12.26	**
TCK154	×	P206	-3.975	n.s	2.12	*	-2.38	n.s	7.23	**	1.86	n.s	-18.45	**
TCK158	×	HP7211	0.037	n.s	2.12	*	1.28	n.s	-6.20	**	0.46	n.s	17.74	**
TCK158	×	P206	6.282	n.s	-3.88	**	-0.13	n.s	-3.29	**	1.23	n.s	-18.50	**
TCK159	×	HP7211	-6.57	*	2.12	*	0.23	n.s	-8.2	**	1.30	n.s	-10.30	**
TCK159	×	P206	-7.718	*	2.40	*	0.23	n.s	-4.63	**	1.70	n.s	7.33	**
Mean			371		88		20.1		28.50		14.1		139.1	
GCA			27.532 to -16.498		2.4 to -7.88		2.53 to -3.78		9.04 to -8.2		3.7 to -2.84		31.97 to -29.54	
Total significant cross			29		54		4		54		8		63	
Positive			14		33		1		29		4		37	
Negative			15		21		3		26		4		26	
CV (0.05)			12.39		1.15		8.55		13.97		9.57		0.6	

Table 2. Heterosis rates of some yield and components of popcorn genotypes.

Female Line	×	Tester Line	Yield (%)	Flowering (%)	Grain moisture (%)	Popping Volume (%)	None popping grain ratio (%)	1000 grain weight (%)
TCK120	×	HP7211	30.59	9.1	-4.2	23.3	-22.96	8.98
TCK120	×	P206	31.78	9.1	4.7	69.9	-21.26	15.04
TCK121	×	HP7211	66.32	9.1	-7.3	27.9	-26.70	10.66
TCK121	×	P206	48.67	9.1	-10.1	69.6	-14.10	23.60
TCK122	×	HP7211	44.67	9.1	-14.4	32.4	-20.60	2.33
TCK122	×	P206	6.79	-3.0	6.6	66.2	-20.24	20.12
TCK123	×	HP7211	52.79	9.1	-18.8	-0.9	-21.47	7.35
TCK123	×	P206	4.45	9.1	-0.5	66.1	-34.21	-0.66
TCK124	×	HP7211	56.67	7.9	-10.4	31.5	-28.80	16.65
TCK124	×	P206	33.86	9.1	3.8	65.6	-26.87	9.75
TCK125	×	HP7211	45.35	1.8	-6.1	2.7	-30.43	3.92
TCK125	×	P206	33.07	9.1	-8.0	61.7	-32.72	5.99
TCK126	×	HP7211	46.19	4.2	-6.6	0.4	-30.02	11.55
TCK126	×	P206	69.94	4.2	-4.0	58.9	-28.46	6.40
TCK127	×	HP7211	65.86	1.8	-9.6	29.7	-31.94	16.83
TCK127	×	P206	-11.33	7.9	-13.9	56.3	-28.15	8.35
TCK128	×	HP7211	53.48	9.1	-16.2	38.4	-25.08	7.05
TCK128	×	P206	37.83	7.9	-5.4	52.5	-25.71	13.12
TCK129	×	HP7211	117.71	7.9	-23.1	36.1	-26.70	5.76
TCK129	×	P206	39.86	9.1	-9.6	49.8	-26.70	8.68
TCK130	×	HP7211	22.21	9.1	-8.7	22.4	-27.75	-4.80
TCK130	×	P206	19.77	9.1	1.2	47.4	-36.04	-4.69
TCK131	×	HP7211	100.37	9.1	-6.1	5.4	-27.23	5.15
TCK131	×	P206	24.07	9.1	-6.8	42.3	-21.54	20.41
TCK132	×	HP7211	28.13	9.1	-3.5	31.2	-8.38	-2.35
TCK132	×	P206	67.38	4.2	-5.6	40.4	-14.43	23.23
TCK133	×	HP7211	131.26	9.1	-0.9	22.3	-15.18	2.26
TCK133	×	P206	72.02	9.1	-9.2	38.8	-33.37	1.85
TCK134	×	HP7211	88.27	9.1	-4.9	7.8	-21.12	-15.15
TCK134	×	P206	18.26	9.1	-1.6	33.3	-50.41	-18.06
TCK135	×	HP7211	118.23	9.1	2.6	20.4	-22.51	-5.07
TCK135	×	P206	86.53	4.2	-6.8	33.3	-28.15	8.17
TCK136	×	HP7211	105.90	9.1	-3.5	32.4	-39.56	-5.07
TCK136	×	P206	86.75	7.9	2.4	33.3	-34.43	-1.23
TCK137	×	HP7211	59.79	9.1	-2.1	5.0	-38.22	-15.17
TCK137	×	P206	37.22	4.2	-6.4	33.2	-26.19	8.78
TCK138	×	HP7211	125.98	1.8	0.2	40.4	-29.72	24.07
TCK138	×	P206	104.48	1.8	-4.7	33.1	-30.60	5.12
TCK139	×	HP7211	70.80	-0.6	-8.7	33.3	-32.46	8.78
TCK139	×	P206	40.86	5.5	-6.4	33.1	-41.22	-8.01
TCK141	×	HP7211	44.28	0.6	-3.8	14.1	-30.89	-15.18
TCK141	×	P206	-5.46	0.6	-6.1	33.1	-12.35	27.89
TCK143	×	HP7211	132.19	0.6	-9.2	24.2	-30.89	-5.13
TCK143	×	P206	64.01	1.8	0.7	31.5	-41.26	-9.69
TCK144	×	HP7211	38.52	9.1	-1.6	7.8	-23.93	-4.69
TCK144	×	P206	114.73	3.0	-18.1	31.2	-36.58	-2.34
TCK145	×	HP7211	31.37	6.1	-0.7	5.0	-26.70	-2.45
TCK145	×	P206	0.64	4.2	-10.6	29.7	-26.70	8.17
TCK146	×	HP7211	63.77	9.1	-11.8	9.6	-21.29	9.17
TCK146	×	P206	36.71	6.7	-6.1	29.7	-45.79	-15.10
TCK148	×	HP7211	57.75	6.7	0.9	13.2	-22.51	1.13
TCK148	×	P206	40.69	9.1	-12.7	27.6	-29.88	6.01
TCK151	×	HP7211	38.26	6.7	0.2	34.2	-24.08	5.69
TCK151	×	P206	9.38	6.7	3.8	22.3	-33.14	1.94
TCK152	×	HP7211	178.05	0.6	-6.1	4.1	-22.66	-2.31
TCK152	×	P206	80.27	6.7	-1.2	20.5	-29.15	7.12
TCK153	×	HP7211	97.36	9.1	1.6	5.5	-21.53	-2.65
TCK153	×	P206	38.61	9.1	3.3	14.1	-28.15	8.23
TCK154	×	HP7211	92.78	9.1	-1.2	0.5	-16.06	-10.70
TCK154	×	P206	42.53	9.1	-16.5	14.1	-36.17	-6.03
TCK158	×	HP7211	86.65	9.1	0.7	21.0	-19.35	-10.73
TCK158	×	P206	153.83	1.8	-5.9	9.5	-21.64	16.28
TCK159	×	HP7211	74.22	4.2	-4.2	7.5	-18.15	8.48
TCK159	×	P206	22.42	9.1	-1.4	0.4	-38.19	-4.32
	Mean		59.63	6.52	-5.29	28.70	-27.48	3.73
	Positive		62	62	14	63	0	40
	Negative		2	2	62	1	64	24

Table 3. Heterobeltiosis rates of some yield and components of popcorn genotypes.

Female Line	×	Tester Line	Yield (%)	Flowering (%)	Grain moisture (%)	Popping Volume (%)	None popping grain ratio (%)	1000 grain weight (g)
TCK120	×	HP7211	23.93	8.4	-7.5	22.7	-24.55	7.70
TCK121	×	HP7211	57.84	8.4	-10.5	31.8	-25.37	9.36
TCK122	×	HP7211	37.29	8.4	-17.3	30.9	-26.37	1.13
TCK123	×	HP7211	45.00	8.4	-21.6	0.0	-25.04	6.09
TCK124	×	HP7211	48.68	7.2	-13.4	37.7	-32.34	15.28
TCK125	×	HP7211	37.93	1.2	-9.3	21.8	-33.89	2.70
TCK126	×	HP7211	38.73	3.6	-9.8	30.6	-28.81	10.24
TCK127	×	HP7211	57.39	1.2	-12.7	7.3	-30.35	15.45
TCK128	×	HP7211	45.65	8.4	-19.1	31.8	-23.36	5.79
TCK129	×	HP7211	106.60	7.2	-25.7	39.7	-41.29	4.52
TCK130	×	HP7211	15.97	8.4	-11.8	13.6	-42.57	-5.92
TCK131	×	HP7211	90.15	8.4	-9.3	7.3	-33.21	3.91
TCK132	×	HP7211	21.60	8.4	-6.8	9.1	-35.82	-3.50
TCK133	×	HP7211	119.46	8.4	-4.3	33.6	-12.94	1.05
TCK134	×	HP7211	78.66	8.4	-8.2	5.0	-19.40	-16.15
TCK135	×	HP7211	107.10	8.4	-0.9	20.5	-30.35	-6.19
TCK136	×	HP7211	95.40	8.4	-6.8	69.1	-27.72	-6.19
TCK137	×	HP7211	51.64	8.4	-5.5	65.4	-30.85	-16.17
TCK138	×	HP7211	114.45	1.2	-3.2	64.8	-31.34	22.61
TCK139	×	HP7211	62.09	-1.2	-11.8	58.2	-35.32	7.50
TCK141	×	HP7211	36.92	0.0	-7.0	51.8	-33.51	-16.18
TCK143	×	HP7211	120.34	0.0	-12.3	46.7	-34.33	-6.24
TCK144	×	HP7211	31.46	8.4	-5.0	39.7	-34.33	-5.81
TCK145	×	HP7211	24.67	5.4	-4.1	32.7	-26.51	-3.60
TCK146	×	HP7211	55.41	8.4	-14.8	32.7	-27.86	7.88
TCK148	×	HP7211	49.70	6.0	-2.5	32.5	-25.43	-0.06
TCK151	×	HP7211	31.21	6.0	-3.2	32.5	-20.24	4.45
TCK152	×	HP7211	163.86	0.0	-9.3	30.6	-30.35	-3.46
TCK153	×	HP7211	87.30	8.4	-1.8	29.1	-26.80	-3.79
TCK154	×	HP7211	82.94	8.4	-4.5	21.8	-26.37	-11.75
TCK158	×	HP7211	77.13	8.4	-2.7	13.6	-25.21	-11.78
TCK159	×	HP7211	65.34	3.6	-7.5	9.0	-22.22	7.21
TCK120	×	P206	25.06	8.4	1.1	27.3	-10.93	13.68
TCK121	×	P206	41.09	8.4	-13.2	-1.4	-26.54	22.14
TCK122	×	P206	1.34	-3.6	3.0	2.3	-19.77	18.71
TCK123	×	P206	-0.88	8.4	-3.9	29.1	-44.63	-1.83
TCK124	×	P206	27.03	8.4	0.2	35.5	-18.34	8.45
TCK125	×	P206	26.28	8.4	-11.1	5.0	-24.87	4.74
TCK126	×	P206	61.27	3.6	-7.3	21.8	-17.04	5.14
TCK127	×	P206	-15.85	7.2	-16.8	19.9	-18.15	7.07
TCK128	×	P206	30.80	7.2	-8.6	4.5	-12.50	11.79
TCK129	×	P206	32.72	8.4	-12.7	32.7	-17.58	7.40
TCK130	×	P206	13.66	8.4	-2.3	23.6	-26.78	-5.81
TCK131	×	P206	17.74	8.4	-10.0	4.5	-22.50	18.99
TCK132	×	P206	58.84	3.6	-8.9	12.7	-34.36	21.78
TCK133	×	P206	63.25	8.4	-12.3	3.6	-4.45	0.65
TCK134	×	P206	12.23	8.4	-5.0	0.0	-25.59	-19.02
TCK135	×	P206	77.01	3.6	-10.0	7.0	-18.15	6.90
TCK136	×	P206	77.22	7.2	-1.1	68.8	-29.18	-2.39
TCK137	×	P206	30.22	3.6	-9.5	65.3	-12.39	7.50
TCK138	×	P206	94.04	1.2	-8.0	61.0	-28.57	3.88
TCK139	×	P206	33.67	4.8	-9.5	55.6	-19.77	-9.10
TCK141	×	P206	-10.28	0.0	-9.3	49.1	-20.12	26.39
TCK143	×	P206	55.64	1.2	-2.7	41.6	-2.12	-10.75
TCK144	×	P206	103.78	2.4	-20.9	38.2	-34.41	-3.49
TCK145	×	P206	-4.50	3.6	-13.6	32.7	-20.88	6.90
TCK146	×	P206	29.73	6.0	-9.3	32.6	-25.34	-16.10
TCK148	×	P206	33.51	8.4	-15.7	32.5	-19.77	4.76
TCK151	×	P206	3.80	6.0	0.2	30.9	-28.73	0.74
TCK152	×	P206	71.07	6.0	-4.5	29.1	-4.08	5.86
TCK153	×	P206	31.54	8.4	-0.2	27.0	-12.07	6.96
TCK154	×	P206	35.26	8.4	-19.3	20.0	-21.70	-7.14
TCK158	×	P206	140.88	1.2	-9.1	13.6	-39.47	14.92
TCK159	×	P206	16.17	8.4	-4.8	0.0	-30.98	-5.45
	Mean		51,49	5,88	-8.52	28.12	-25.25	2.51
	Positive		60	62	4	63	0	39
	Negative		4	2	60	1	64	25

Table 4. Dominance effect rates of some yield and components of popcorn genotypes.

Female Line	×	Tester Line	Yield (%)	Flowering (%)	Grain moisture (%)	Popping Volume (%)	None popping grain ratio (%)	1000 grain weight (g)
TCK120	×	HP7211	3.47	3.84	0.35	2.00	0.92	5.63
TCK120	×	P206	-3.63	4.63	2.82	1.64	4.39	12.34
TCK121	×	HP7211	2.79	4.63	-0.56	-2.43	0.71	21.93
TCK121	×	P206	-1.24	3.84	-1.61	3.95	-0.01	7.51
TCK122	×	HP7211	4.26	3.84	-2.68	-7.85	-0.50	18.04
TCK122	×	P206	-8.28	-15.38	3.39	-2.97	1.75	-1.82
TCK123	×	HP7211	-1.98	3.84	-4.01	1.26	-0.22	-5.24
TCK123	×	P206	-8.72	4.63	1.27	14.70	-0.37	3.80
TCK124	×	HP7211	2.32	1.84	-1.48	1.64	-0.52	6.42
TCK124	×	P206	-3.25	4.63	2.54	14.96	-1.67	14.22
TCK125	×	HP7211	-0.49	-8.16	-0.21	-2.05	0.32	2.21
TCK125	×	P206	-3.39	4.63	-0.98	16.43	-0.74	-0.04
TCK126	×	HP7211	-0.95	-3.38	-0.35	-2.43	0.82	2.67
TCK126	×	P206	-1.31	-4.16	0.22	7.39	-3.10	8.51
TCK127	×	HP7211	-5.87	-8.16	-1.27	4.86	-1.53	14.41
TCK127	×	P206	-11.65	2.63	-2.74	1.64	1.09	4.96
TCK128	×	HP7211	-2.43	3.84	-3.24	9.43	0.19	3.46
TCK128	×	P206	-2.51	2.63	-0.20	4.04	-0.80	10.30
TCK129	×	HP7211	12.35	2.63	-5.28	10.98	-0.37	1.89
TCK129	×	P206	-4.31	3.84	-1.47	0.52	0.22	5.33
TCK130	×	HP7211	-5.41	4.63	-0.99	-0.20	4.16	-9.64
TCK130	×	P206	-6.15	3.84	1.77	16.32	-1.15	-9.93
TCK131	×	HP7211	0.28	3.84	-0.21	3.12	2.00	18.47
TCK131	×	P206	-5.07	4.63	-0.63	8.35	-0.09	1.21
TCK132	×	HP7211	15.04	3.84	0.56	1.72	2.85	-7.19
TCK132	×	P206	2.99	-3.38	-0.28	1.64	-4.57	21.63
TCK133	×	HP7211	8.57	3.84	1.34	-5.75	-3.62	-2.33
TCK133	×	P206	3.85	4.63	-1.33	1.64	6.73	-2.03
TCK134	×	HP7211	6.87	4.63	0.14	-6.11	-0.70	-24.62
TCK134	×	P206	-2.38	3.84	0.92	-0.57	1.51	-21.53
TCK135	×	HP7211	14.87	3.84	2.39	12.02	1.03	-10.24
TCK135	×	P206	6.55	-3.38	-0.63	-11.29	-0.34	4.65
TCK136	×	HP7211	13.89	3.84	0.56	14.90	-4.89	-10.24
TCK136	×	P206	6.59	2.63	2.12	-11.83	0.36	-5.87
TCK137	×	HP7211	9.12	3.84	0.99	1.01	-5.15	-21.55
TCK137	×	P206	-2.62	-3.38	-0.49	-1.68	-2.39	5.34
TCK138	×	HP7211	10.15	-8.16	1.69	-3.20	0.95	1.23
TCK138	×	P206	9.89	-7.38	0.01	1.73	-1.47	22.40
TCK139	×	HP7211	19.07	-12.16	-0.99	-9.26	0.94	-13.47
TCK139	×	P206	-1.94	-1.38	-0.49	5.34	-2.13	5.28
TCK141	×	HP7211	2.71	-10.16	0.49	-3.42	-1.25	-20.40
TCK141	×	P206	-10.56	-9.38	-0.42	-9.82	-3.49	26.64
TCK143	×	HP7211	5.39	-10.16	-1.13	-7.60	-0.80	-15.45
TCK143	×	P206	2.36	-7.38	1.63	0.27	-2.49	-9.14
TCK144	×	HP7211	12.45	3.84	1.13	1.73	0.65	-8.64
TCK144	×	P206	11.80	-5.38	-4.01	-8.32	-2.48	-7.22
TCK145	×	HP7211	-2.13	-1.16	1.41	-2.67	-3.06	4.55
TCK145	×	P206	-9.43	-3.38	-1.75	2.38	-0.13	-6.14
TCK146	×	HP7211	-1.11	3.84	-1.90	4.58	1.57	6.87
TCK146	×	P206	-2.72	0.63	-0.42	1.17	-0.75	-21.52
TCK148	×	HP7211	1.20	0.63	1.90	0.27	1.15	-2.13
TCK148	×	P206	-3.85	3.84	-2.39	-9.43	-0.62	3.28
TCK151	×	HP7211	0.40	-0.16	1.69	-9.25	0.29	-1.28
TCK151	×	P206	-7.80	0.63	2.54	-5.98	1.87	2.98
TCK152	×	HP7211	23.57	-9.38	-0.21	0.90	1.09	-5.98
TCK152	×	P206	3.63	-0.16	1.06	-8.33	-0.99	4.52
TCK153	×	HP7211	7.71	3.84	2.11	-9.43	0.20	5.76
TCK153	×	P206	-2.36	4.63	2.40	1.70	1.49	-6.36
TCK154	×	HP7211	1.00	3.84	1.27	-10.35	-0.17	-10.21
TCK154	×	P206	-1.63	4.63	-3.51	13.15	3.39	-15.38
TCK158	×	HP7211	6.57	4.63	1.83	-11.28	0.85	14.78
TCK158	×	P206	1.58	-8.16	-0.35	-5.98	2.25	-15.41
TCK159	×	HP7211	-3.71	-4.00	0.35	-14.91	2.36	-8.58
TCK159	×	P206	-5.37	4.80	0.28	-8.42	3.08	6.11
Mean			1,55	0,01	-0.08	-0.05	-0.02	0.00
x>1			29	37	20	31	18	34
-1<x<+1			30	22	16	27	16	29
-1>x			4	5	28	6	30	1

4. Conclusion

Positive and negative heterosis and heterobeltiosis values were obtained for all traits examined in the study. According to the results, heterosis rates for grain yield and popping volume traits were -11.33-178.05%, -0.9-69.9%, respectively. Similalry, heterobeltiosis rates grain yield and popping volume traits were -15.85-163.86% and -14.4-69.1%, respectively. Positive heterosis rates were obtained above the desired (>20%) heterosis values in for grain yield and popping volume traits, which are the most important selection criteria. It is thought that high heterosis values are related to the genetic variability of inbred lines. In addition, overdominance and partial dominance were effective in grain yield and popping volume. The highest GCA value in grain yield trait in the experiment was obtained from 'TCK152' × 'P206' hybrid with 27.53 tons/ha, and from 'TCK125' × 'P206' hybrid with 9.04% in popping volume. Different lines ranked first in grain yield and popping volume traits, which are the main selection criteria in popcorn breeding. However, 'TCK129', 'TCK 135', 'TCK136' and 'TCK144' inbred lines had higher grain yield GCA and above average popping volume values. These results indicate that in a short time, new commercial popcorn hybrids can be developed which can be planted in Türkiye. This suggests that popcorn inbred lines that stand out in both traits have the highest genetic differences. There are no defined heterotic groups in popcorn. Identification of heterotic groups through genetic studies will contribute to increasing heterosis success.

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Conflict of interest

The authors declare no conflicts of interest.

Authorship contribution statement

E.Ö: Methodology, Planning and conducting the experiment, performing statistical analyses, Writing-Original draft preparation, Writing- Reviewing and Editing. B.U: Conducting the experiment, taking observations and measurements.

References

Alhadi R. A. A., Hadid, M. L., & Ahmad, S.A., (2013). Potence ratio and path analysis for yield and quality traits in single crosses of maize *(Zea mays* L.) produced in syria. *Jordan J. Agri. Sci*. 9(2): 153-161.

Amanullah, S., Jehan, M., Mansoor A., & Khan, M.A. (2011). Heterosis studies in diallel crosses of maize. *Sarhad J. Agric*., 27(2): 207-211.

Babo, R., Nair, S.K., Kumar, A.; Rao, H.S. Verma, P., Gahalain, A., Singh, I.S., Gupta, H.S. (2006). Mapping QTLs for popping ability in a popcorn × flint corn cross. *Theor. Appl. Genet*., 112, 1392–1399.

Begum, S., Alam, S. S., Omy, S. H., Amiruzzaman, M., & Rohman, M. M. (2018). Inheritance and combing ability in maize using a 7x7 diallel cross. *Journal of Plant Breeding and Crop Science*, *10*(9), 239-248. https://doi.org/10.5897/JPBCS2018.0750

Cabral, P. D. S., do Amaral Júnior, A. T., Freitas, I. L. D. J., Ribeiro, R.M., & Silva, T. R. D. C. (2016). Cause and effect of quantitative characteristics on grain expansion capacity in popcorn. *Rev. Cienc. Agron*. 47, 108–117. https://doi.org/10.5935/1806-6690.20160013

Coan, M. M. D., Barth, R. J. P., Kuki, M.C., Júnior, A. T. A., Figueiredo, A. S. T., Scapim, C. A., & Warburton, M. (2019). Inheritance study for popping expansion in popcorn vs. flint corn genotypes. *Agron. Appl. Genet*. Resour. 111, 1–10.

Daros M, Amaral Júnior AT, Pereira MG, Santos FS, et al. (2004). Correlações entre caracteres agronômicos em dois ciclos de seleção recorrente em milho-pipoca. *Ciencia Rural* 34, 1389-1394. http://dx.doi.org/10.1590/S0103847820040005000010

De Lima, V.J., do Amaral Júnior, A.T., Kamphorst, S. H., Bispo, R. B., Leite, J.T., Santos, T. D. O., Schmitt, K. F. M., Chaves, M. M., de Oliveira, U. A., & Santos, P. H. A. D. (2019). Combined dominance and additive gene effects in trait ınheritance of drought-stressed and full irrigated popcorn. *Agronomy*, *9* (12), 782. https://doi.org/10.3390/agronomy9120782

de Oliveira, G. H. F., Murray, S. C., Cunha Júnior, L. C., de Lima, K. M. G., Morais, C .D. L. M. D., Teixeira, G.H.d.A., & Môro, G.V. (2020). Estimation and classification of popping expansion capacity in popcorn breeding programs using NIR spectroscopy. *J. Cereal Sci*. 91, 102861. https://doi.org/10.1016/j.jcs.2019.102861

Dhliwayo, T. (2008. *Genetic mapping and analysis of traits related to improvement of popcorn*. (Publication No. 15863) [Doctoral dissertation, Iowa State University]. http://lib.dr.iastate.edu/rtd

Effa, E. B., Uwah, D. F. & Ukeh, D. A. (2011). Yield response of popcorn (*Zea mays* L. var. everta) to nitrogen and lime amendment in a southeastern rainforest environment of nigeria. *American Journal of Plant Physiolog,y* 6: 304-311.

Flint-Garcia S. A, Buckler E.S, Tiffin. P., Ersoz, E,, & Springer N.M. (2009). Heterosis is prevalent for multiple traits in diverse maize germplasm. *PLoS ONE*, 4(10): e7433.

Freıtas Júnıor, S.P., A.T. Amaral Júnıor, M.G, PereıraCruz, C.D. & Scapım C.A. (2006). Capacidade combinatória em milho pipoca por meio de dialelo circulante. *Pesquisa Agropecuária Brasileira*, 41: 1599-1607.

Freitas, J. S. P. F., Amaral, J. A. T., Rangel, R. M. & Viana, A. P. (2009). Genetic gains in popcorn by full-sib recurrent selection. *Crop Breeding and Applied Biotechnology*, 9: 1-7.

Guillen-de la Cruz, P., de la Cruz-Lázaro, E., Castañon-Najera, G., Osorio-Osorio, R., Brito-Manzano, N.P., Lozanodel Río, A. & López-Noverola, U. (2009) Aptitud Combinatoria General y Especifica de Germoplasma Tropical de Maíz. *Tropical and Subtropical Agroecosystems*, 10, 101-107.

Guerrero, C., Gallegos Robles, M., Luna Ortega, J., Castillo, I., Vázquez, C., Carrillo, M., Resendez, A. & Torres, A. (2014) Combining Ability and Heterosis in Corn Breeding Lines to Forage and Grain. *American J. Plant Sciences*, 5, 845-856. http://dx.doi. org/10.4236/ajps.2014.56098.

Ghosh, A. Das, P. K., Ghosh, A., & Kundagrami, S. (2018). Heterosis, potence ratio and genetic distance for yield and yield contributing traits in single cross maize hybrids. January 2018; *Maydica* 63(1).

Gosai, M. A., Kuchhadiya, G. V., Brahmbhatt, B. N. & Bhalala, K. N. (2017). Study of combining ability in diallel crosses of maize (Zea mays L.) for grain yield and quality traits. Int. *J. Res. Agric. Sci*., 4(2): 2348–3997.

Guimaraes, P. D., Paterniani, G. Z., Luders, R. R., de Souza, A. P., Laborda, P. R., & Oliveira K. M. (2007). Correlation between the heterosis of maize hybrids and genetic divergence among lines. Pesqui. Agropecu. *Bras. J*. 42(6):811-816.

Guimarães, A. G., do Amaral Júnior, A. T., Pena, G. F., de Almeida Filho, J. E., Pereira, M. G., & Santos, P. H. A. D. (2019). Genec gains in the popcorn population uenf-14: Developing the ninth generation of intrapopulation recurrent selectionton. *Rev. Caatinga*, *32*, 625–633.

Kamphorst, S. H., do Amaral Junior, A.T., de Lima, V. J., Carena, M. J., Azeredo, V. C., Mafra, G. S., Santos, P. H. A. D., Leite, J.T. Schmitt, K. F. M., & dos Santos Junior, D. R. (2021). Driving sustainable popcorn breeding for drought tolerance in brazil. *Front. Plant Sci*. 12, 1942.

Khan, M. U., Shah, S. M. A., Rahman, H., Iqbal, A., & Aslam, E. (2019). Evaluation of maize hybrids for yield and maturity traits. *Sarhad J. of Agri*. 35(1): 7-12.

Kumar G.P, Prashanth, Y., Reddy, V.N., Kumar, S.S., & Rao P. V. (2014). Heterosis for grain yield and its component traits in maize (*Zea mays L.*). Int. J. *Inbred App. Biosci*. 2(1), 106-111.

Kumar, M., Singhamsetti, A., Madankar, K., & Devesh, P. (2023). Deciphering of popcorn (*Zea mays* var. everta) heterosis for early maturity, yield and popping expansion volume *Across Different Environments Biological Forum – An International Journal,* 15(2): 909-915.

Larısh, L. L. B., & Brewbaker J.L. (1999). Diallel analyses of temperate and tropical popcorns Maydica, Bergamo, n.44, p. 279-284.

Li, Y. L., Dong, Y. B., Niu, S. Z., & Cui, D. Q. (2007). QTL for popping characteristics in popcorn. *Plant Breeding, 126*, 509–514.

Mafra, G.S., do Amaral Junior, A.T., Vivas, M., dos Santos, J.S., Silva, F. H. d. L. E., Guimarães, A.G., & Pena, G. F. (2018). The combining ability of popcorn S7 lines for puccinia polysora resistance purposes. *Bragantia*, 77, 519–526.

Mather, K. (1949). Biometrical Genetics. Dover Press, New York.

Mather K., & Jinks J.L, (1971). Biometrical Genetics, Chapman and Hall Ltd. (2nd ed.), London

Özata E., Öztürk A., Erdal Ş., & Pamukçu, M. (2024). New single hybrid popcorn variety ATASAM. *Ekin Journal*, 10(1), 59-63.

Pereıra, M.G. & Amaral Júnıor, A.T. (2001). Estimation of genetic components in popcorn based on the nested design. *Crop Breeding and Applied Biotechnology* 1: 3-10

Rangel R.M, Amaral Júnior A.T. & Freitas Jr S.P, (2011). Associação entre características agronômicas e capacidade de expansão em população de milho pipoca sob seleção recorrente. *Cienc. Agrotec*. 35: 225-233. http://dx.doi. org/10.1590/S1413-70542011000200001

Rinaldi, D.A., Carpentieri-Pipolo, V., Gerage, A.C., Ruas, C. F., Fonseka, J. N. S., Souza, A., Souza, S. G. H. & Garbuglo, D. D. (2007). Correlacao entre heterose e divergencia genética estimadas por cruzamentos dialelicos e marcadores RAPD em populacoes de milho-pipoca. *Bragantia*, 66: 183-192.

Santos Junior, D. R. d., Amaral Junior, A. T. d., Lima, V. J. d. Leite, J. T., Bispo, R. B. Azeredo, V. C., Almeida Filho, J. E. d., Kamphorst, S. H., Viana, F. N., & Ribeiro, R. M. (2023). Recurrent ınterpopulation selection in popcorn: from heterosis to genetic Gains. *Plants*, 12, 1056. https://doi.org/10.3390/ plants12051056

Santos, J.S., Amaral Júnior, A.T., Vivas, M., Mafra, G.S., Pena, G.F., Silva, F. H. L., & Guimarães, A. G. (2017). Genetic control and combining ability of agronomic attributes and northern leaf blight-related attributes in popcorn. *Gen. Mol. Res*. 16, 1–11.

Santos, J.S., de Souza, Y.P., Vivas, M., Amaral Junior, A.T., Filho, J.E.d.A., Mafra, G.S., Viana, A.P., Gravina, G.d.A., & Ferreira, F. R. A. (2020). Genetic merit of popcorn lines and hybrids for multiple foliar diseases and agronomic properties. *Funct. Plant Breed*. J. 2, 32–47.

Sahid, Z. D., Syukur, M., & Maharijaya, A. (2020). Combining ability and heterotic effects of chili pepper (*Capsicum annuum* L.) genotypes for yield components and capsaicin content. Sabrao *J. Breed. Genet*. 52(4): 390401.

Smith, H. H. (1952). Fixing Transgressive Vigour in *Nicotiana rustica*, “Heterosis”. Iowa State College Press, Ames

Soni, N. V., & S. M. Khanorkar (2013). Association of genetic divergence with heterosis, combining ability and mean value for quantitative traits in popcorn (*Zea mays* var. Everta). *The Bioscan*, 8(4): 1363-1367.

Sweley, J.C. Rose, D. J., & Jackson, D. J. (2013). Quality traits and maize. Sarhad J. Agric. 27(2): 207-211.

TDÖDTT (2018). Tarımsal değerleri ölçme denemeleri teknik talimatı. https://www.tarimorman.gov.tr/BUGEM/ TTSM/Belgeler/Tescil/Teknik%20Talimatlar/S%C4% B1cak %20%C4%B0klim%20Tah%C 4%B1llar %C4% B1 /MISIR_TEKNIK_TALIMATI.pdf

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Determination of seed yield, yield components, and seed quality characteristics of some soybean (*Glycine max* (L.) Merr.) genotypes in Samsun, Türkiye*

Seyit Ahmet EROL[1]*, Celal BAYRAM[1], Meral ERGİN[1], Mehmet ERDOĞMUŞ[1]

[1]Black Sea Agricultural Research Institute, Samsun, Türkiye

***Corresponding author e-mail:** s.ahmeterol@gmail.com

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Abstract: This study assessed seed yield, yield components, and seed quality traits of some soybean (*Glycine max* (L.) Merr.) genotypes in Samsun, Türkiye. The experiment was conducted in two locations (Çarşamba and Bafra) in 2022. A total of twenty-four soybean genotypes were utilized, including three standards varieties (ARISOY, ATAEM-7, and SAMSOY), and twenty-one lines (F8 generation) developed by cross breeding. As a result of study, seed yield values ranked between 4.69 t ha-1 (KA14-09-04) and 3.38 t ha-1 (KA14-01-01), whereas plant height varied between 122.9 cm (ARISOY) and 92.8 cm (KA14-02-06). First pod height ranged from 17.9 cm (ATAEM-7) to 12.5 cm (KA14-02-04), and the number of pods per plant varied between 113.5 (KA14-09-04) and 69.3 (KA14-01-01). In addition, hundred seed weight differed between 20.70 g (KA14-05-04) and 15.59 g (KA14-01-14). Finally, seed oil content ranged from 22.64% (KA14-05-01) to 20.22% (KA14-02-06), and the seed protein content values varied between 45.28% (KA14-02-06) to 41.55% (KA14-05-01). In conclusion, KA14-09-04 and KA14-05-04 produced the highest seed yield in the ecological conditions of Samsun province in Türkiye. It can be suggested that the Bafra location is more suitable for high oil production, while the Çarşamba is more suitable for high protein production in terms of suitability for soybean cultivation.

Keywords: Soybean lines, cross breeding, seed yield, oil concentration, protein concentration.

Türkiye Samsun'da bazı soya (*Glycine max* (L.) Merr.) genotiplerinin verim, verim komponentleri ve tohum kalite özeliklerinin belirlenmesi

Öz: Bu çalışmanın amacı, bazı soya (*Glycine max* (L.) Merr.) genotiplerinin Samsun ili koşullarında tohum verimi, verim komponentleri ve tohum kalite özelliklerini belirlemektir. Çalışma 2022 yılında, iki (Çarşamba ve Bafra) lokasyonda yürütülmüştür. Çalışmada üç tescilli çeşit (ARISOY, ATAEM-7 ve SAMSOY) ve melezleme yoluyla geliştirilmiş yirmi bir adet ileri kademe (F8) hat kullanılmıştır. Çalışma sonucunda, verim 4.69 t ha-1 (KA14-09-04) – 3.38 t ha-1 (KA14-01-01), bitki boyu 122.9 cm (ARISOY) – 92.8 cm (KA14-02-06), ilk bakla yüksekliği 17.9 cm (ATAEM-7) – 12.5 cm (KA14-02-04), bitkide bakla sayısı 113.5 adet (KA14-09-04) – 69.3 adet (KA14-01-01) aralığında değerler almıştır. Ayrıca yüz tohum ağırlığı 20.70 g (KA14-05-04) – 15.59 g (KA14-01-14) arasında değişmiştir. Son olarak ham yağ oranı %22.64 (KA14-05-01) – %20.22 (KA14-02-06) ve ham protein oranı %45.28 (KA14-02-06) – %41.55 (KA14-05-01) aralığında değişim göstermiştir. Çalışma sonucunda Türkiye'nin Samsun ili ekolojik koşullarında KA14-09-04 ve KA14-05-04 hatları en yüksek tane verimine sahip olmuştur. Son olarak soya ekiminde amaca uygun olması bakımından yüksek yağ eldesi için Bafra lokasyonunun, yüksek protein eldesi için ise Çarşamba lokasyonunun daha uygun olduğu önerilebilir.

Anahtar kelimeler: Soya hattı, melezleme, tohum verimi, yağ içeriği, protein içeriği

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1. Introduction

Soybean is an industrial plant that serves as a cost-effective and high-quality source of plant-based protein and oil on a global scale. Soybeans are an ideal raw materials for feed production, oil extraction, and biodiesel production with an oil content of 20% and a protein content of 40%. Additionally, they are used in cosmetics, nutraceuticals and for medicinal purposes (de Siqueira Gesteira et al., 2018). Due to the presence of essential amino acids, soybean proteins have high nutritional value (Singh et al., 2008). Soybean oil consists of 16% saturated and 84% unsaturated fatty acids, with an average fatty acid composition of 52% linoleic acid, 25% oleic acid, 12% palmitic acid, 6% linolenic acid and 5% stearic acid (Eren et al., 2012).

Türkiye is a suitable country for soybean production under both main crop and second crop conditions, especially in areas where irrigation is not an issue. With proper production planning, the soybean cultivation area and seed yield can be increased. Another method to increase production is through breeding programs aimed at developing new varieties that are superior in terms of seed yield and agricultural traits. This approach would allow for higher seed yields per unit area. While developing new varieties, it is crucial to set priorities according to specific conditions and direct breeding efforts accordingly. It is also a scientific fact that newly developed lines or varieties may show different results under different ecological conditions. In addition to genotypic traits, environmental factors play a significant role in the seed yield performance of genotypes. Therefore, data obtained from trials conducted in different environments should be evaluated. Variance analyses applied to such trials allow for the assessment of differences between genotypes and the performance of genotypes across different environments. For this reason, regional adaptation studies are a critical breeding stage, particularly for new varieties or lines. This is also true for soybean breeding, where the identification of genotypes with superior yield and quality traits across different environmental conditions is essential for success. Soybean was first cultivated in the Black Sea Region of Türkiye, it continues to be grown in the province of Samsun within this region. Therefore, it may be beneficial to develop soybean genotypes suitable for the region and to increase studies on improving yield and quality traits in different locations.

This study aims to determine the seed yield, yield components and seed quality traits of some soybean genotypes as a main crop under the ecological conditions of Samsun Province.

2. Materials and Methods

2.1. Experimental area climate and soil properties

This study was conducted in 2022 at two locations belonging to the Black Sea Agricultural Research Institute: Çarşamba (41° 13' N, 36° 40' E, altitude of 15 m) and Bafra (41° 36' N, 35° 55' E, altitude of 20 m). The soil characteristics of the locations where the study was carried out were determined in the Soil Science Laboratory of the Black Sea Agricultural Research Institute Directorate.

The soil texture of the Çarşamba experimental field is clay-loam, while the soil texture of the Bafra experimental field falls within the clay class. The organic matter levels of both locations are similar (1.33, 1.38) (Table 1).

According to meteorological data, the average temperature values in both locations are similar. The lowest average temperature was recorded in May, while the highest occurred in August. The total rainfall was 227 mm in the Bafra location and 276 mm in the Çarşamba location. The monthly rainfall was higher in Çarşamba during September, whereas it was higher in Bafra during June. In both locations, the lowest rainfall was recorded in July (Figure 1, 2).

Table 1. Soil properties of Çarşamba and Bafra locations.

Location	Years	Soil Texture	pH	EC Mmhos/cm	Organic matter%	P_2O_5 (kg/da)	K_2O (kg/da)	$CaCO_3$ (%)
Çarşamba	2022	Clay-Loam	7.54	0.023	1.33	3.86	113	5.99
Bafra	2022	Clay	7.57	0.051	1.38	2.57	103	9.52

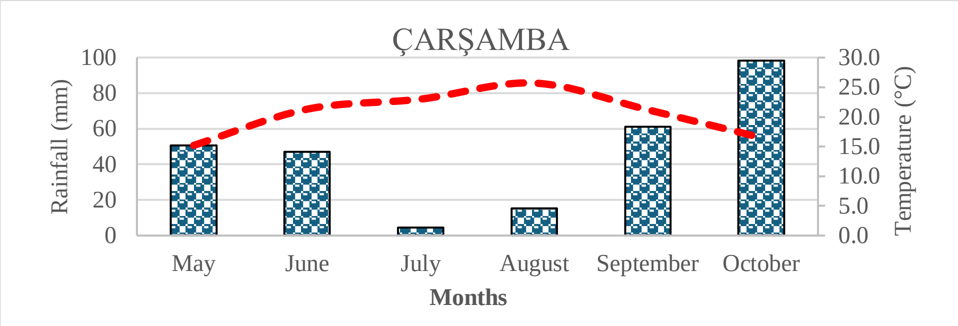

Figure 1. Monthly average temperature (°C) and rainfall (mm) data for Çarsamba location.

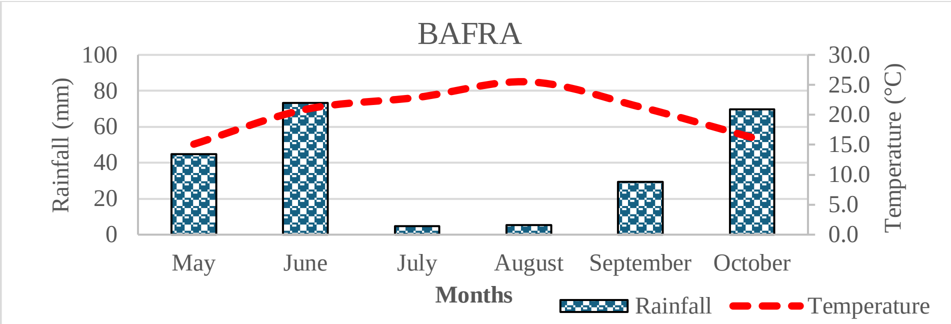

Figure 2. Monthly average temperature (°C) and rainfall (mm) datas for Bafra location.

2.2. Experimental design and management

The experiment was conducted in a randomized complete block design with three replications. The material used in the study consisted of 21 soybean lines (at the F8 generation) belonging to maturity group III, developed through cross breeding as part of the "Soybean Breeding Research Project for the Black Sea Region" conducted at the Black Sea Agricultural Research Institute. The standard varieties used were ARISOY, ATAEM-7, and SAMSOY.

The plot dimensions were planned with a plot length of 5 m, a row spacing of 70 cm, intrarow spacing of 4 cm and 4 rows per plot. The area of each plot was 14 m^2. Pre-sowing, the seeds were inoculated with *Bradyrhizobium japonicum* bacterial inoculant. Sowing was performed on May 17, 2022, using a seed drill. Based on the soil analysis, 40 kg N ha^{-1} and 8 kg P_2O_5 ha^{-1} fertilizers were applied before sowing. Irrigation was carried out four different times, based on the water requirements of plant and soil moisture status, using a sprinkler irrigation system. To control weeds, chemical control was applied before sowing using herbicide containing *pendimethalin* (300 ml/da) and mechanical control was conducted once during the V2 (second trifoliolate) stage. The plants were harvested using a parcel combine harvester on November 2, 2022.

2.3. Plant sampling and measurements

At the physiological maturity stage (R7), plant height and the height of the first pod were measured using a meter stick on 10 randomly selected plants from each plot. The number of pods per plant was determined by counting the pods on each plant. For seed yield calculation, two rows (7 m^2) located in the center of each plot were used. The 100 seed weight was determined by counting and weighing 100 seeds from the harvested seeds in each plot, with four replications. After that, 100 seed weight of plants was determined by calculating the average values of the weighing measurements. The seed yield and 100 seed weight of the plots were adjusted and calculated based on a seed moisture content of 13.5%. The oil and protein content of the seeds were determined using the NIRS (Near Infrared Range Spectrometer) method with an XDS MasterLab Rapid Content Analyzer NIR Spectrometer (FOSS, Denmark), calibrated appropriately. Approximately 500 g of seed samples from each plot were used for this analysis. Finally, the oil and protein content of the seeds were calculated as a percentage based on seed weight.

2.4. Statistical analysis

Analysis of variance (ANOVA) was used to analyze the data according to randomized complete block using

SAS-JMP 13.0 program. The differences among means were compared by Tukey's HSD multiple range test ($p \leq 0.05$).

3. Results and Discussion

Significant differences were found between the genotypes for plant height, first pod height, number of pods, 100-seed weight, oil and protein content (P<0.01), and seed yield (P<0.05). Significant differences were also observed between the Çarşamba and Bafra locations in terms of first pod height, seed yield, 100-seed weight, oil, and protein content (P<0.01), and number of pods (P<0.05). However, no statistically significant difference was found between locations for plant height. According to the genotype x environment interaction values, differences were found in terms of first pod height, number of pods (P<0.01), and protein content (P<0.05), although no significant differences were observed for plant height, seed yield, 100-seed weight, and oil content (Table 2).

Table 2. Combined (Çarşamba-Bafra locations) ANOVA statistical results.

Parameters	Genotype			Location			Genotype x Location Int.		
	DF	MS	Prob.	DF	MS	Prob.	DF	MS	Prob.
Plant height	23	383.99	0.0003**	1	3094.14	0.0743ns	23	113.23	0.6953ns
First pod height	23	19.33	<.0001**	1	697.84	0.0006**	23	16.64	<.0001**
Pod number	23	860.55	<.0001**	1	2704.00	0.0268*	23	683.41	<.0001**
Seed yield	23	6439.66	0.0183*	1	8464.88	0.0011**	23	2041.04	0.9210ns
100 seed weight	23	9.09	<.0001**	1	125.53	0.0028**	23	1.19	0.8104ns
Oil content	23	2.47	0.0002**	1	60.50	0.0011**	23	1.19	0.1481ns
Protein content	23	3.48	0.0014**	1	121.78	0.0003**	23	2.61	0.0232*

**:*p<0.01*; *:*p<0.05*; ns: not significant

Table 3. Combined (Çarşamba-Bafra locations) ANOVA statistical results and statistical groups for plant height.

Genotypes	Plant Height (cm)			
	Çarşamba	Bafra	Mean	
KA14-01-01	113.3	107.5	110.4**	ab
KA14-01-03	121.2	100.5	110.9	ab
KA14-01-07	109.0	108.0	108.5	ab
KA14-01-14	108.0	98.0	103.0	ab
KA14-02-01	120.2	109.8	115.0	ab
KA14-02-02	117.0	106.5	111.8	ab
KA14-02-04	99.3	89.5	94.4	b
KA14-02-05	99.3	92.2	95.8	b
KA14-02-06	94.8	90.8	92.8	b
KA14-02-07	102.7	98.7	100.7	ab
KA14-03-01	117.7	101.2	109.5	ab
KA14-05-01	120.5	107.0	113.8	ab
KA14-05-04	128.3	102.2	115.3	ab
KA14-05-05	110.0	98.5	104.3	ab
KA14-05-07	119.2	96.2	107.7	ab
KA14-05-08	94.0	96.0	95.0	b
KA14-06-02	121.3	97.3	109.3	ab
KA14-09-01	106.5	106.7	106.6	ab
KA14-09-02	110.7	112.0	111.4	ab
KA14-09-03	115.0	108.8	111.9	ab
KA14-09-04	118.8	114.7	116.8	ab
ARISOY	132.5	113.2	122.9	a
ATAEM-7	115.0	119.5	117.3	ab
SAMSOY	101.0	98.2	99.6	ab
Mean	112.3	103.0	107.7	
CV (%)			10.9	

**:*p<0.01*; *CV*: coefficient of variation; Mean data for each trait followed by different letters differ significantly at p < 0.05 using Tukey's HSD test

According to the results of the variance analysis conducted with the data obtained from the study, significant differences were found between locations for all traits except plant height (Table 2). Therefore, a combined variance analysis was not performed for the other traits analyzed, except for plant height. Instead, the variance analysis for the locations was conducted separately, and the means were grouped accordingly.

3.1. Plant height (cm)

The highest plant height was observed in the ARISOY variety (122.9 cm), while the lowest plant height was recorded in the KA14-02-06 line (92.8 cm) (Table 3).

The effect of location on plant height was statistically non-significant (Table 2). The average plant height at the Çarşamba location was 112.3 cm, while it was 103.0 cm at Bafra. Average for both locations was 107.7 cm (Table 3). Several studies conducted in different regions of Turkey support the findings of this study (Sincik et al., 2009; Güngör and Üstün, 2015; Kocatürk et al., 2019; Kınay et al., 2020).

3.2. First pod height (cm)

The average first pod height was 17.1 cm in Çarşamba and 12.7 cm in Bafra and a statistically significant difference (P<0.01) was determined between the locations (Table 4). The reason why the first pod height was higher in Çarşamba location compared to Bafra location may be due to soil properties and rainfall regime (Figure. 1, 2 and Table 1). According to the average values of the locations, the highest first pod height was determined in ATAEM-7 variety (17.9 cm) while the lowest first pod height was determined in KA14-02-04 line (12.5 cm) (Table 4).

Table 4. ANOVA results and statistical groups for first pod height and pod number in Çarşamba and Bafra locations.

Genotypes	First Pod Height (cm)					Pod number (piece)				
	Çarşamba		Bafra		Mean	Çarşamba		Bafra		Mean
KA14-01-01	15.0**	bc	10.3**	bc	12.7	49.7**	f	88.8**	a-f	69.3
KA14-01-03	15.0	bc	10.8	bc	12.9	93.2	a-e	58.3	g	75.8
KA14-01-07	13.3	c	12.5	a-c	12.9	86.0	b-e	77.0	e-g	81.5
KA14-01-14	22.5	a	11.5	bc	17.0	80.7	c-f	72.3	fg	76.5
KA14-02-01	20.0	a-c	13.7	ac	16.9	112.5	a-c	102.8	ab	107.7
KA14-02-02	16.7	a-c	11.8	bc	14.3	113.8	a-c	80.5	c-f	97.2
KA14-02-04	15.0	bc	10.0	bc	12.5	104.7	a-d	85.5	a-f	95.1
KA14-02-05	13.3	c	12.5	a-c	12.9	90.5	a-e	105.3	a	97.9
KA14-02-06	14.2	bc	11.7	bc	13.0	108.0	a-d	79.0	d-g	93.5
KA14-02-07	16.7	a-c	13.3	a-c	15.0	89.3	a-c	74.8	fg	82.1
KA14-03-01	16.7	a-c	8.8	c	12.8	106.0	a-d	100.0	a-d	103.0
KA14-05-01	20.8	ab	14.2	a-c	17.5	113.2	a-c	77.5	e-g	95.4
KA14-05-04	20.0	a-c	12.5	a-c	16.3	119.2	ab	100.3	a-d	109.8
KA14-05-05	16.7	a-c	12.3	a-c	14.5	85.2	c-e	77.0	e-g	81.1
KA14-05-07	20.0	a-c	15.0	a-c	17.5	77.5	d-f	104.2	a	90.9
KA14-05-08	14.2	bc	13.2	a-c	13.7	101.8	a-d	75.3	e-g	88.6
KA14-06-02	22.5	a	11.2	bc	16.9	101.3	a-d	96.8	a-e	99.1
KA14-09-01	15.8	a-c	12.0	bc	13.9	59.5	e-f	88.8	a-f	74.2
KA14-09-02	18.3	a-c	14.5	a-c	16.4	98.0	a-d	103.0	ab	100.5
KA14-09-03	13.3	c	15.3	ab	14.3	111.8	a-c	100.2	a-d	106.0
KA14-09-04	15.8	a-c	15.0	a-c	15.4	120.7	a	106.3	a	113.5
ARISOY	19.2	a-c	12.2	a-c	15.7	82.7	c-f	102.3	a-c	92.5
ATAEM-7	17.5	a-c	18.3	a	17.9	99.5	a-d	72.5	f-g	86.0
SAMSOY	17.5	a-c	11.7	bc	14.6	114.2	a-c	82.0	b-f	98.1
Mean	17.1**	A	12.7	B	14.9	96.6*	A	87.9	B	92.3
CV (%)	14.0		7.6			11.0		7.9		

**:*p<0.01*; *:*p<0.05*; *CV*: coefficient of variation; Mean data for each trait followed by different letters differ significantly at p < 0.05 using Tukey's HSD test

First pod height is a significant agricultural trait for machine harvesting. The development and productivity of pods on the soybean plant are not uniform. Pods located at the lower part of the plant tend to be more productive than those at the upper part. Therefore, the pods situated at the lower section of the plant are particularly important in terms of harvest seed yield and it can lead to losses during harvesting. Ramteke et al. (2012) and Tkachuk (2019) reported that the first pod height in soybeans should be at least 12 cm for efficient mechanical harvesting. The first pod height values possessed by the genotypes in this study are within the suitable range for machine harvesting. The first pod height values obtained in this study are consistent with the findings of Beiküfner et al. (2019), Şahin and İşler (2021), and Richard et al. (2023).

3.3. Pod number (piece)

A significant difference (p<0.05) was determined between the locations in terms of the number of pods per plant. It was determined that the average number of pods was higher in Çarşamba location than in Bafra location. According to the average values of the locations, the number of pods varied between 69.3 pieces (KA14-01-01) and 113.5 pieces (KA14-09-04) (Table 4). Arslanoğlu and Aytaç (2010) conducted a study across eight different locations in Türkiye with eight different soybean genotypes and found an average pod number of 73.2 at the Çarşamba location and 87.3 at the Bafra location. Yıldırım et al. (2022), in a two-year study in İzmir involving ten soybean genotypes, including seven lines and three varieties, reported that the number of pods per plant varied between 84.0 and 129.6. The number of pods per plant in this study was found to be close to the values determined by the researchers. Gümüş and Beyyavaş (2020), in their study conducted in the ecological conditions of Mardin province with ten different soybean varieties, reported a pod count ranging from 81.5 to 133.9, indicating that they achieved higher pod count values than those obtained in our study. Conversely, Andırman and Baran (2023), in their research with seven different soybean varieties in Batman province, found a pod count ranging from 31.3 to 49.2, which is lower than the values obtained in our study. In conclusion, genotype and location differences in soybean have a significant impact on the number of pods per plant.

3.4. Seed yield (t ha^{-1})

The average seed yield at the Çarşamba location was determined to be 3.34 t ha-1, while at the Bafra location, it was found to be 4.87 t ha-1. The average seed yield across both locations was calculated to be 4.11 t ha-1. According to the average of the locations, the lowest seed yield was determined in KA14-01-01 (3.38 t ha-1) and KA14-01-03 (3.61 t ha-1) lines, while the highest seed yield was determined in KA14-09-04 (4.69 t ha-1) and KA14-05-04 (4.66 t ha-1) lines. The seed yields of the standard varieties in the study were determined as follows: SAMSOY (4.24 t ha-1), ARISOY (4.16 t ha-1), and ATAEM-7 (3.96 t ha-1) (Table 5). As a result of the study, although the number of pods per plant affecting the seed yield was higher at Çarşamba location, the average seed yield value was higher at Bafra location. This was due to the higher 100 seed weight value at Bafra location compared to Çarşamba location. The significant difference in seed yield between the locations may be attributed to the higher amount of rainfall recorded at the Bafra location in June compared to the Çarşamba. Eren et al. (2012) conducted a study with 22 genotypes, at the Antalya location, where they reported seed yields ranging from 3.11 to 4.48 t ha-1. Çubukçu et al. (2021) investigated 14 different soybean genotypes as a second crop at four different locations: Adana, Antalya, Şanlıurfa, and İzmir. Their findings indicated seed yields in Adana ranging from 3.32 to 3.95 t ha-1, in Antalya from 2.63 to 3.61 t ha-1, in Şanlıurfa from 3.16 to 4.15 t ha-1, and in İzmir from 3.09 to 3.68 t ha-1. Göksoy et al. (2019) evaluated 15 soybean genotypes over three years at three different locations: Samsun, Konya, and Bursa. The seed yield varied between 2.65 and 4.22 t ha-1 at the Bursa location, 2.33 and 3.85 t ha-1 at the Konya location, and 3.44 and 4.08 t ha-1 at the Samsun location. The results indicated that the seed yield values obtained from the Bafra location were higher compared to findings from other studies conducted in Türkiye.

3.5. 100 seed weight (g)

A significant difference ($p<0.01$) was determined between the locations in terms of 100 seed weight. The average 100 seed weight was determined higher in the Bafra location than in the Çarşamba location. According to the average values of the locations, the lowest 100 seed weight was determined in the KA14-01-14 line (15.59 g) while the highest was determined in the KA14-05-04 line (20.70 g) (Table 5). The results of some studies conducted in different regions of the world (Flajšman et al., 2019; Staniak et al., 2021; Thakur et al., 2022; Rani et al., 2023), as well as some studies conducted in Türkiye (Gül and Arslanoğlu, 2020; Ekberli and Kars, 2021; Bakal et al., 2021), are consistent with the findings obtained in this study.

3.6. Oil content (%)

The average oil content was determined to be %20.72 in the Çarşamba location and %22.02 in the Bafra location. The overall average for both locations was calculated to be %21.37. The reason why the oil content of the seeds was higher in the Bafra location than in the Çarşamba location may be due to ecological differences. According to the average values of the locations, the KA14-05-01 line (22.64%) was determined as promising in terms of oil content (Table 6). Arslanoğlu et al. (2011) reported significant effects of genotypes, locations, and genotype x location interactions on the oil content of seeds in their study conducted across various locations in the provinces of Tokat (Erbaa and Turhal), Amasya (Gökhöyük and Suluova), Samsun (Çarşamba and Bafra), and Sinop (Kabalı and Boyabat). Additionally, the researchers found that the average oil content of soybean genotypes varied between %20.52 and %21.80, with average oil contents of %21.00 and %21.58 in the Çarşamba and Bafra locations of Samsun province, respectively. The findings of our research are supported by results from other studies conducted in various regions of Türkiye regarding the oil content of seeds (Gölükçü, 2019; Erbil, 2020; Kaya, 2020).

3.7. Protein content (%)

The protein content was determined to be 44.24% at the Çarşamba location and 42.41% at the Bafra location. Based on the average of the locations, the protein content of the seeds is approximately 43.33%. The protein content was determined to be low in the Bafra location where the fat content is high, and the protein content was determined to be high in the Çarşamba location where the fat content is low. According to the results of the average of the locations, the protein content of the seeds ranged from 41.55% (KA14-05-01) to 45.28% (KA14-02-06). Among the standard varieties included in the study, the protein contents were ranked as follows: ARISOY (44.18%), ATAEM-7 (43.28%), and SAMSOY (42.93%). (Table 6). The findings related to the protein content of the seeds in our study are similar to the results reported by Yıldırım and İlker (2018), and Demir et al. (2020). However, the findings in de Siqueira Gesteira et al. (2018), Yılmaz et al. (2022), and Sümer (2022) seed yielded lower protein content results compared to those obtained in our study. We believe that the differences between the results of our study and those found in the literature are due to the variations in ecological conditions under which the studies were conducted and the differences in the genotypes examined.

Table 5. ANOVA results and statistical groups for seed yield and 100 seed weight in Çarşamba and Bafra locations.

Genotypes	Seed Yield (t ha^{-1})					100 Seed Weight (g)				
	Çarsamba		Bafra		Mean	Çarşamba		Bafra		Mean
KA14-01-01	2.73*	d	4.02*	d	3.38	17.22**	a-c	20.48**	a-c	18.85
KA14-01-03	3.02	cd	4.20	cd	3.61	14.94	bc	17.12	cd	16.03
KA14-01-07	2.96	cd	5.00	a-c	3.98	17.16	a-c	19.54	a-d	18.35
KA14-01-14	3.14	bc	4.34	cd	3.74	14.40	c	16.77	d	15.59
KA14-02-01	3.57	ab	5.40	ab	4.49	19.32	ab	21.28	ab	20.30
KA14-02-02	3.18	bc	5.21	a-c	4.20	17.20	a-c	18.79	a-d	18.00
KA14-02-04	3.10	bc	5.16	a-c	4.13	18.94	a-c	20.61	ab	19.78
KA14-02-05	3.63	ab	4.55	bc	4.09	18.29	a-c	21.26	ab	19.78
KA14-02-06	3.45	ab	4.73	a-c	4.09	17.38	a-c	19.70	a-d	18.54
KA14-02-07	3.27	bc	4.47	bc	3.87	18.26	a-c	19.51	a-d	18.89
KA14-03-01	3.87	a	4.91	a-c	4.39	18.69	a-c	19.68	a-d	19.19
KA14-05-01	3.40	ab	4.90	a-c	4.15	16.22	a-c	19.57	a-d	17.90
KA14-05-04	3.94	a	5.37	ab	4.66	19.64	a	21.75	a	20.70
KA14-05-05	3.15	bc	4.57	bc	3.86	17.86	a-c	18.74	a-d	18.30
KA14-05-07	3.31	bc	4.79	a-c	4.05	19.74	a	21.10	ab	20.42
KA14-05-08	2.88	cd	5.12	a-c	4.00	18.71	a-c	19.40	a-d	19.06
KA14-06-02	3.60	ab	5.11	a-c	4.36	17.90	a-c	19.07	a-d	18.49
KA14-09-01	2.89	cd	4.35	cd	3.62	17.74	a-c	19.42	a-d	18.58
KA14-09-02	3.47	ab	5.26	a-c	4.37	19.10	ab	20.74	ab	19.92
KA14-09-03	3.41	ab	5.54	ab	4.48	16.61	a-c	20.60	ab	18.61
KA14-09-04	3.79	a	5.58	a	4.69	19.05	ab	21.16	ab	20.11
ARISOY	3.44	ab	4.88	a-c	4.16	17.48	a-c	18.24	b-d	17.86
ATAEM-7	3.35	bc	4.56	bc	3.96	17.98	a-c	18.57	a-d	18.28
SAMSOY	3.58	ab	4.90	a-c	4.24	17.85	a-c	19.39	a-d	18.62
Mean	3.34	B	4.87**	A	4.11	17.82	B	19.69**	A	18.76
CV (%)	14.0		11.7			8.1		5.3		

**:*p<0.01*; *:*p<0.05*; *CV*: coefficient of variation; Mean data for each trait followed by different letters differ significantly at p < 0.05 using Tukey's HSD test.

Table 6. ANOVA results and statistical groups for oil content and protein content in Çarşamba and Bafra locations.

Genotypes	Oil Content (%)					Protein Content (%)				
	Çarşamba		Bafra		Mean	Çarşamba		Bafra		Mean
KA14-01-01	21.08**	ab	22.12**	ab	21.60	43.73**	ac	42.03*	ab	42.88
KA14-01-03	20.32	ac	21.90	ab	21.11	44.77	ab	43.09	ab	43.93
KA14-01-07	21.11	ab	22.23	ab	21.67	44.34	ab	42.33	ab	43.34
KA14-01-14	21.07	ab	21.67	ab	21.37	43.95	ac	44.07	a	44.01
KA14-02-01	22.27	ab	22.49	ab	22.38	42.71	bc	42.50	ab	42.61
KA14-02-02	22.06	ab	21.46	ab	21.76	43.31	bc	43.32	ab	43.32
KA14-02-04	21.20	ab	22.57	ab	21.89	44.84	ab	41.94	ab	43.39
KA14-02-05	20.61	ac	23.13	a	21.87	44.08	ac	41.62	ab	42.85
KA14-02-06	19.31	c	21.13	ab	20.22	46.09	a	44.47	a	45.28
KA14-02-07	20.45	ac	21.30	ab	20.88	44.66	ab	42.81	ab	43.74
KA14-03-01	20.17	bc	23.19	a	21.68	45.24	ab	40.21	b	42.73
KA14-05-01	22.42	a	22.86	ab	22.64	42.23	c	40.88	ab	41.55
KA14-05-04	20.51	ac	22.00	ab	21.26	44.29	ab	42.12	ab	43.21
KA14-05-05	21.84	ab	22.89	ab	22.37	42.53	bc	41.79	ab	42.16
KA14-05-07	19.88	bc	22.54	ab	21.21	44.37	ab	41.45	ab	42.91
KA14-05-08	20.43	ac	22.03	ab	21.23	45.01	ab	42.58	ab	43.80
KA14-06-02	19.97	bc	21.69	ab	20.83	45.12	ab	42.65	ab	43.89
KA14-09-01	20.31	ac	21.45	ab	20.88	44.59	ab	42.94	ab	43.77
KA14-09-02	20.64	ac	22.21	ab	21.43	45.94	a	42.33	ab	44.14
KA14-09-03	19.75	bc	20.73	b	20.24	42.58	bc	43.05	ab	42.82
KA14-09-04	19.61	bc	21.65	ab	20.63	44.35	ab	41.92	ab	43.14
ARISOY	19.26	c	21.81	ab	20.54	46.08	a	42.27	ab	44.18
ATAEM-7	21.64	ab	21.95	ab	21.80	43.82	ac	42.73	ab	43.28
SAMSOY	21.45	ab	21.45	ab	21.45	43.24	bc	42.62	ab	42.93
Mean	20.72	B	22.02**	A	21.37	44.24**	A	42.41	B	43.33
CV (%)	5.1		3.5			2.8		2.7		

**:*p<0.01*; *:*p<0.05*; *CV*: coefficient of variation; Mean data for each trait followed by different letters differ significantly at p < 0.05 using Tukey's HSD test

4. Conclusion

According to the research findings, KA14-09-04 and KA14-05-04 soybean lines stood out as the ones with the highest seed yield in the ecological conditions of Samsun province of Türkiye. It can be suggested that the Bafra location is more suitable for high oil production, while the Çarşamba location is more suitable for high protein production in terms of suitability for soybean cultivation. Finally, it was concluded that conducting similar studies in more locations and over extended periods would be beneficial for assessing the impact of environmental factors on soybean genotypes regarding seed yield, yield criteria, and seed quality traits.

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Conflict of interest

The authors declare no conflicts of interest.

Authorship contribution statement

S.A.E: Methodology, Planning and conducting the experiment, performing statistical analyses, Writing-Original draft preparation, Writing- Reviewing and Editing. C.B: Conducting the experiment, taking observations and measurements. M.ERG: Conducting the experiment, taking observations and measurements. M.ERD: Conducting the experiment, taking observations and measurements.

References

Andırman M, Baran N., (2023). Some soybean [*Glycine max* L. (Merill)] varieties determination of cultivation possibilities of as main crop. *BSJ Agri*, 6(4): 373-379. https://doi.org/10.47115/bsagriculture.1298590

Arslanoglu, F. and Aytac S., (2010). Determination of stability and genotype x environment interactions of some agronomic properties in the different soybean (*Glycine max*. (L) Merrill) cultivars. *Bulg. J. Agric. Sci*., 16: 181-195

Arslanoglu, F., Aytac, S., & Oner, E. K. (2011). Effect of genotype and environment interaction on oil and protein content of soybean (*Glycine max (L.) Merrill*) seed. *African Journal of Biotechnology*, *10*(80), 18409-18417. https://doi.org/10.5897/AJB10.1879

Bakal, H., Bağırkan, Ö., & Arıoğlu, H. (2021). İkinci ürün koşullarında yetiştirilen soya bitkisinin farklı gelişme dönemlerinde tepe büyüme noktasında oluşan mekanik zararın tohum verimi ile bazı tarımsal özellikler üzerine etkileri. *Mustafa Kemal Üniversitesi Tarım Bilimleri Dergisi*, *26*(1), 117-127. https://doi.org/10.37908/mkutbd.770096

Beiküfner, M., Hüsing, B., Trautz, D., Kühling, I., (2019). Comparative harvest efficiency of soybeans between cropping systems affected by first pod height and plant length. Org. Farming 5, 3–13. https://doi.org/10.12924/of2019.05010003

Cubukcu, P., Kocatürk, M., Ilker, E., Kadiroğlu, A., Vurarak, Y., Şahin, Y., ... & Sincik, M. (2021). Stability analysis of some soybean genotypes using parametric and nonparametric methods in multi-environments. *Turkish Journal of Field Crops*, *26*(2), 262-271. https://doi.org/10.17557/tjfc.1033363

De Siqueira Gesteira, G., Bruzi, A. T., Zito, R. K., Fronza, V., & Arantes, N. E. (2018). Selection of early soybean inbred lines using multiple indices. *Crop Science*, *58*(6), 2494-2502. https://doi.org/10.2135/cropsci2018.05.0295

Demir, B., Şahin, M., Aydoğan, S., Akçacık, A. G., Güçbilmez, Ç. M., Hamzaoğlu, S., ... & Gümüşçü, G. (2020). Konya koşullarında yetiştirilen soya (*Glycine max L.*) hat ve çeşitlerine ait verim ve bazı kalite özelliklerinin değerlendirilmesi. *Kahramanmaraş Sütçü İmam Üniversitesi Tarım ve Doğa Dergisi*, 1021-1029. https://doi.org/10.18016/ksutarimdoga.vi.697770

Ekberli, İ., & Kars, N. (2021). Soya bitkisinin (*Glycine max L. Merill*) verim parametreleri ile bazı fiziksel toprak özellikleri arasındaki deneysel ilişkilerin belirlenmesi. *Toprak Bilimi ve Bitki Besleme Dergisi*, *9*(2), 42-53. https://doi.org/10.33409/tbbbd.989044

Erbil, E. (2020). Bazı ileri soya (*Glycine max L.*) hatlarının şanlıurfa ikinci ürün koşullarında verim ve kalite özellikleri yönünden değerlendirilmesi. *ISPEC Journal of Agricultural Sciences*, *4*(2), 272-284. https://doi.org/10.46291/ISPECJASvol4iss2pp137-149

Eren, A., Kocatürk, M., Hoşgün, E. Z., & Azcan, N. (2012). Bazı soya hat ve çeşitlerinde tohum verimi, yağ-protein ve yağ asitleri içerikleri ve aralarındaki ilişkilerinin belirlenmesi. *Süleyman Demirel Üniversitesi, Ziraat Fakültesi Dergisi*, *7*(1), 1-9.

Flajšman, M., Šantavec, I., Kolmanič, A., Košmelj, K., & Kocjan-Ačko, D. (2019). Agronomic performance and stability of seed, protein and oil yields of seven soybean cultivars determined in field experiments in Slovenia. *Genetika*, *51*(1), 31-46. https://doi.org/10.2298/GENSR1901031F

Goksoy, A. T., Sincik, M., Erdogmus, M., Ergin, M., Aytac, S., Gumuscu, G., & Senyigit, E. (2019). The parametric and non-parametric stability analyses for interpreting genotype by environment interaction of some soybean genotypes. *Turkish Journal of Field Crops*, *24*(1), 28-38. https://doi.org/10.17557/tjfc.562637

Gölükcü, M., Tokgöz, H., & Kocatürk, M. (2019). Bazı soya (*Glycine max L.*) çeşit ve hatlarının yağ içeriği ile yağ asitleri bileşimlerinin araştırılması. *Akademik Ziraat Dergisi*, *8*(2), 283-290. https://doi.org/10.29278/azd.538613

Gül, S., & Arslanoğlu, F. (2020). The influence of organic fertilizer applications on seed yield and some quality properties of soybean grown as second crop. *Uşak Üniversitesi Fen ve Doğa Bilimleri Dergisi*, *4*(2), 114-126. https://doi.org/10.47137/usufedbid.804807

Gümüş, Z., & Beyyavaş, V. (2020). Bazı Soya [*Glycine max. L. Merill*] Çeşitlerinin mardin ili ekolojik koşullarında ikinci ürün olarak yetiştirilebilme olanakları. *ADYUTAYAM (Tarımsal Uygulama ve Arazi Yönetimi Uygulama ve Araştırma Merkezi) Dergisi*, *8*(2), 44-51.

Güngör, H., & Üstün, A. (2015). Konya ekolojisinde iki farklı sıra aralığının bazı soya (*Glycine max (L.) Merill*) genotiplerinde verim ve bazı verim unsurlarına etkisi. *Journal of Agricultural Faculty of Gaziosmanpaşa University (JAFAG)*, *32*(2), 100-106. https://doi.org/10.13002/jafag841

Kaya, A. R. (2020). Ana ürün olarak yetiştirilen bazı soya fasulyesi *(Glycine max. (L.) Merrill*) çeşitlerinin önemli kalite özelliklerinin belirlenmesi. *Kahramanmaraş Sütçü İmam Üniversitesi Tarım ve Doğa Dergisi*, *23*(4), 1012-1020. https://doi.org/10.18016/ksutarimdoga.vi.691990

Kinay, A., Mehtap, S., & Erdem, K. (2020). Determining the performance of some soybean genotypes in middle black sea transitional zone. *International Journal of Agricultural and Life Sciences*, *6*(3), 293-299. http://dx.doi.org/10.22573/spg.ijals.020.s122000100

Kocaturk, M., Cubukcu, P., Goksoy, A. T., Sıncık, M., Ilker, E., Kadıroglu, A., ... & Yıldırım, U. A. (2019). GGE biplot analysis of genotype× environment interaction in soybean grown as a second crop. *Turkish Journal of Field Crops*, *24*(2), 145-154. https://doi.org/10.17557/tjfc.615175

Ramteke, R., Singh, D., & Murlidharan, P. (2012). Selecting soybean *(Glycine max)* genotypes for insertion height of the lowest pod, the useful trait for combine harvester. *Indian Journal of Agricultural Sciences*, *82*(6), 511.

Rani, R., Raza, G., Ashfaq, H., Rizwan, M., Shimelis, H., Tung, M. H., & Arif, M. (2023). Analysis of genotype× environment interactions for agronomic traits of soybean (*Glycine max [L.] Merr.)* using association mapping. *Frontiers in Genetics*, *13*, 1090994. https://doi.org/10.3389/fgene.2022.1090994

Richard, D., Leimbrock-Rosch, L., Keßler, S., Stoll, E., & Zimmer, S. (2023). Soybean yield response to different mechanical weed control methods in organic agriculture in Luxembourg. *European Journal of Agronomy*, *147*, 126842. https://doi.org/10.1016/j.eja.2023.126842

Sincik, M., Göksoy, A. T., & Turan, Z. M. (2009). Soybean seed yield performances under different cultural practices. *Turkish Journal of Agriculture and Forestry*, *33*(2), 111-118. https://doi.org/10.3906/tar-0807-26

Singh, P.; Kumar, R.; Sabapathy, S.N.; Bawa, A.S. Functional and edible uses of soy protein products. Compr. Rev. Food Sci. Food Saf. 2008, 7, 14–28. https://doi.org/10.1111/j.1541-4337.2007.00025.x

Staniak, M., Czopek, K., Stępień-Warda, A., Kocira, A., & Przybyś, M. (2021). Cold stress during flowering alters plant structure, yield and seed quality of different soybean genotypes. *Agronomy*, *11*(10), 2059. https://doi.org/10.3390/agronomy11102059

Sümer, F. Ö. (2022). Soya tane verimi ve protein oranının çinko uygulaması ile geliştirilmesi. *Turkish Journal of Agriculture-Food Science and Technology*, *10*(11), 2188-2195. https://doi.org/10.24925/turjaf.v10i11.2188-2195.5449

Şahin, C. B., & İşler, N. (2021). Foliar applied zinc and iron effects on yield and yield components of soybean: Determination by PCA analysis. *Communications in Soil Science and Plant Analysis*, *52*(3), 212-221. https://doi.org/10.1080/00103624.2020.1854297

Thakur, R., Kumari, V., Pal, A., & Rana, P. (2022). Genetic variability analysis for agro-morphological and seed yield component traits of soybean (*Glycine max (L.) Merrill*) genotypes under mid hill zone of Himachal Pradesh. *International Journal of Environment and Climate Change*, *12*(11), 1559-1567. https://doi.org/10.9734/ijecc/2022/v12i1131139

Tkachuk, C., 2019. Soybean pod height: İnfluence of genetics, environment and management [WWW Document]. Manit. Pulse Soybean Grow. URL https://www.manitobapulse.ca/2019/06/soybean-pod-height-influence-of-genetics-environment-and-management/)

Yıldırım, A., & İlker, E. (2018). Ege Bölgesi'nde ikinci ürün koşullarında bazı soya çeşit ve hatlarının verim ve agronomik özellikleri ile kalite özelliklerinin belirlenmesi. *Adnan Menderes Üniversitesi Ziraat Fakültesi Dergisi*, *15*(2), 1-8. https://doi.org/10.25308/aduziraat.393970

Yıldırım, A., İlker, E., Ekren, S., Yavaş, İ., Isayeva, D., & Bayraktar, Ö. H. (2022). A breeding study to develop early maturing soybean crosses suitable for double cropping. *Turkish Journal of Field Crops*, *27*(2), 182-187. https://doi.org/10.17557/tjfc.1146550

Yılmaz, A., Yılmaz, H., Soydemir, H. E., & Çiftçi, V. (2022). Soya (*Glycine max L.*)'da PGPR ve AMF uygulamalarının verim özellikleri ve protein içeriğine etkisi. *Uluslararası Tarım ve Yaban Hayatı Bilimleri Dergisi*, *8*(1), 108-118.

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The effect of some beneficial bacteria on the yield of pepper plants

Zeliha KAYAASLAN[1]*, Sabriye BELGÜZAR[2], Yusuf YANAR[2], Mustafa MİRİK[3]

[1]Yozgat Bozok University, Faculty of Agriculture, Department of Plant Protection, Yozgat, Türkiye
[2]Tokat Gaziosmanpaşa University, Faculty of Agriculture, Department of Plant Protection, Tokat, Türkiye
[3]Tekirdağ Namik Kemal University, Faculty of Agriculture, Department of Plant Protection, Tekirdağ, Türkiye

***Corresponding author e-mail:** zeliha.kayaaslan@bozok.edu.tr

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Abstract: This study investigated plant growth-promoting characteristics of 389 candidate bacterial isolates collected during surveys conducted in 2017 by using nitrogen fixation, phosphorus reduction, and antagonistic activities tests. Six candidate bacterial isolates were identified as a result of the tests. The identification of these species was carried out using the MALDI-TOF MS technique, which identified species as *Enterobacter cloacae*, *E. aerogenes, Bacillus cereus*, *Microbacterium testaceum*, *Pseudomonas putida*, and *Acinetobacter calcoaceticus*. Pot and field trials were conducted using different combinations of these isolates. All isolates were used in the pot experiment, whereas isolates with the highest antagonistic activity and their combinations were used in the field trials. The pot trials were conducted using a randomized block design with five replications, while the field trials were conducted using a randomized complete block design with ten replications. The effects of these isolates on the yield of healthy pepper plants were investigated. Data relating to plant height, root length, stem diameter, number of fruits, plant fresh and dry weight, and root fresh and dry weight were collected. Results of the pot experiment revealed that combinations of *B. cereus* + *P. putida* and *P. putida* + *A. calcoaceticus* resulted in 15% higher yield compared to the control. Similarly, field trials indicated that *P. putida* improved the values of investigated traits by 12.3-37.2%. *Pseudomonas putida* is considered beneficial for future research based on the results of this study.

Keywords: PGPR, yield, bacteria, pepper

Bazı faydalı bakterilerin biber bitkilerinin verimi üzerindeki etkisi

Öz: Bu çalışmada, 2017 yılında yapılan sürveyler sonucunda toplanan 389 aday bakteri izolatının bitki büyümesini teşvik edici özellikleri araştırılmıştır. Elde edilen izolatların bitki gelişimini teşvik etme özelliklerini belirlemek amacıyla azotu bağlama, fosforu indirgeme ve antagonistik etki testleri yapılmıştır. Testler sonucunda altı adet aday bakteri izolatı belirlenmiştir. Bu türler MALDİ-TOF MS tekniği ile *Enterobacter cloacae, Enterobacter aerogenes, Bacillus cereus, Microbacterium testaceum*, *Pseudomonas putida* ve *Acinetobacter calcoaceticus* bakterileri olduğu tanılanmıştır. Saksı ve tarla denemeleri, bu izolatların farklı kombinasyonları kullanılarak yürütülmüştür. Saksı denemesinde tüm izolatlar kullanılırken, tarla denemesinde en yüksek antagonistik etkiye sahip izolatlar ve bunların kombinasyonları kullanılmıştır. Saksı denemeleri tesadüf parselleri deneme desenine göre 5 tekerrür olarak yürütülmüştür. Tarla denemeleri ise tesadüf blokları deneme desenine göre 10 tekerrürlü yürütülmüştür. Bu izolatların sağlıklı biber bitkisinin verim değerlerine etkileri araştırılmıştır. Saksı çalışması ve devamında yürütülen tarla çalışmasında bitki boyu, kök uzunluğu, gövde çapı, meyve sayısı, bitki yaş ağırlığı, bitki kuru ağırlığı, kök yaş ağırlığı ve kök kuru ağırlığı gibi parametreler ölçülmüştür. Sonuç olarak sera denemelerinde *B. cereus* + *P. putida* ile *P. putida* + *A. calcoaceticus* bakterilerin ikili kombinasyon uygulamalarında kontrole göre %15 daha fazla verim elde edilmiştir. Tarla uygulamalarında ise *P. putida* uygulaması değerlendirmeye alınan bitki parametrelerinde %12,3-37,2 arasında değişen oranlarda artışı sağlamıştır. Çalışma sonuçlarına göre özellikle *Pseudomonas putida* ile ileriye dönük çalışmaların yapılmasının yararlı olacağı düşünülmektedir.

Anahtar kelimeler: PGPR, verim, bakteri, biber

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1. Introduction

Antagonistic bacterial isolates that promote plant growth not only activate the defense mechanisms of plants, but also stimulate seed germination, enhance root development, and improve nutrient uptake. Furthermore, they contribute to the plant's resistance to pathogens by producing hormones (Siddiqui, 2005). Different PGPR (plant growth-promoting Rhizobacteria) isolates improve yield and stress tolerance in plants while suppressing soil-borne pathogens (Kloepper et al., 1991). Endophytic bacteria have a high colonization ability in plant roots, leading to reduced stress and increased root development (Hardoim et al., 2008). Isolates belonging to genera Bacillus, Pseudomonas, and Agrobacterium are prominent in biological control as microorganisms associated with soil and plants (Fira et al., 2018). Considering all these properties, the use of PGPR is becoming increasingly important. Kang et al. (2007) selected 23 endophytic bacterial isolates among 150 isolates collected from pepper fields in Chungcheong and Gyeongsang provinces of Korea. These isolates were reported to increase root fresh weight by 73.9% and 41.5%, respectively, by stimulating systemic resistance in the plants. Mirik et al. (2008) isolated 3 Bacillus isolates from soil samples in the rhizosphere of pepper plants, then applied them alone or in combination to the pepper plants. Conequently, their application increased stem diameter, root length, root dry weight, shoot dry weight, and yield by 7-20%, 7-17%, 4.5-23.5%, 16.5-38.5%, and 11-33%, respectively.

This study isolated PGPRs from leaves, stems, root hairs, and rhizosphere regions of healthy pepper plants growing in Tokat Province. Six candidate isolates that could potentially promote plant growth were identified. These isolates identified by MALDI-TOF were *Enterobacter cloacae*, *E. aerogenes*, *Bacillus cereus, Microbacterium testaceum, Pseudomonas putida*, and *Acinetobacter calcoaceticus*, which were tested for their effects on pepper plant development under both greenhouse and field conditions in single, double, and triple combinations.

2. Materials and Methods

2.1. Materials

Samples were taken from 17 fields (7 from Tokat Center and 10 from Erbaa district) during September 2017 to obtain bacteria that promote plant growth. A total 389 candidate isolates were obtained by isolating the soil and capillary roots, stem and leaf parts of the pepper plant with different methods. These candidate isolates were subjected to the phosphate reduction test and 94 isolates with the best zone diameter were recorded. Nitrogen fixation ability test identified 38 candidate isolates (Kayaaslan 2021). Proteomic identification of the isolates determined by tobacco hypersensitivity, potato softening test and antagonistic effect tests were performed by Mustafa Kemal University, Plant Health Clinic Application and Research Center using MALDI-TOF MS technique. The baterial isolates tested were *Enterobacter cloacae, Enterobacter aerogenes, Bacillus cereus, Microbacterium testaceum, Pseudomonas putida*, and *Acinetobacter calcoaceticus*. The 'İstek F1' pepper variety was used in the experiments. Nutrient agar (NA) were used for the development of bacterial isolates.

2.2. Methods

The pot experiment was conducted in the greenhouses of the Research and Application Center at Tokat Gaziosmanpaşa University, while the field study was carried out in the field plots of the same center. Field trials were conducted with the three isolates that gave the best results in the pot experiment (ZE-7, ZE-12, and ZE-13).

2.3. Pot experiments

Pepper seedlings of 'İstek F1' variety in three true leaf stage were used in the pot experiments. The experiment was designed according to a randomized block design with five replications. Candidate bacteria were growen on NA medium at 25°C for 24-48 hours. The treatments are given in Table 1. The roots of the pepper seedlings were immersed in bacterial suspensions ($1x10^6$ cfu/ml) for 1 hour to ensure bacterial colonization. Afterwards, the seedlings were planted in 5-liter plastic pots filled with a soil:peat (1:1:1) mixture, with one plant per pot. The same bacterial suspensions were applied again 10 days after planting (50 ml per plant) to the root region of the plants (Belgüzar et al., 2021). Weekly observations were recorded following the second application throughout the growing season, and the number of fruits and total fruit weight were recorded for each plant. The aboveground and underground parts of the plants were separately collected in polyethylene bags and brought to the laboratory at the end of the production season. Plant height, root length, stem diameter, number of fruits, plant fresh and dry weight, and root fresh and dry weight were recorded.

Table 1. Treatments used in the pot experiments

Treatments	Bacterial isolates
NC	Distilled water (negative control)
ZE-2	*Enterobacter cloacae*
ZE-5	*Enterobacter aerogenes*
ZE-7	*Bacillus cereus*
ZE-8	*Microbacterium testaceum*
ZE-12	*Pseudomonas putida*
ZE-13	*Acinetobacter calcoaceticus*
ZE-7+2	*B. cereus + P. putida*
ZE-7+13	*B. cereus + A. calcoaceticus*
ZE-12+13	*P. putida + A. calcoaceticus*
ZE-7+12+13	*B. cereus + P. putida + A. calcoaceticus*

Table 2. Treatments used in the field experiments

Treatments	Bacterial isolates
NC	Distilled water treatment (negative control)
ZE-7	*Bacillus cereus*
ZE-12	*Pseudomonas putida*
ZE-13	*Acinetobacter calcoaceticus*
ZE-7+12	*B. cereus +P. putida*
ZE-7+13	*B. cereus +A. calcoaceticus*
ZE-12+13	*P. putida + A. calcoaceticus*
ZE-7+12+13	*B. cereus + P. putida+A. calcoaceticus*

2.4. Field trials

The field trials were conducted using three isolates (ZE-7, ZE-12, and ZE-13) that gave the best results in the pots experiments (Table 2). The seedlings of 'İstek F1' pepper variety were used in the field trial. The prepared bacterial suspensions were used to immerse the pepper seedlings roots for 1 hour to ensure bacterial colonization. Afterwards, the seedlings were planted in the field. Ten days after planting, a second bacterial suspension applications were made to the root region of the plants, 50 ml per plant. Plants roots were immersed in sterile distilled water as negative control. The study was set up according to randomized block design with 10 replications. Weekly observations were made throughout the growing season following the second application and the number of fruits and total fruit weight were recorded for each plant. The plants were harvested at the end of the production season and their above- and below-ground were collected separately in polyethylene bags and brought to the laboratory. Measurements for plant height, root length, stem diameter, number of fruits, plant fresh weight, and root fresh weight were taken. Additionally, above- and below-ground parts of the plants were dried, and their dry weights were recorded.

2.5. Statistical analyses

The differences between the applications were compared with ANOVA and Tukey multiple comparison test ($p \leq 0.05$).

3. Results and Discussion

3.1. Pots experiments

The effects of candidate bacterial isolates on plant height, root length, stem diameter, fruit number, plant fresh weight, plant dry weight, root fresh weight, and root dry weight in pepper are presented in Table 3. All treatments increased plant development to varying degrees, but this increase was statistically non-significant. The highest effect on plant height (15.2% increase compared with control) was observed for ZE-7+12 (*Bacillus cereus* + *Pseudomonas putida*). Root length was increased by 7.2%, 4.6%, and 1.1% with the applicaitons of ZE-7+12, ZE-7+13, and ZE-12+13, respectively. The highest effect on stem diameter (10.2% increase) was noted for ZE-12+13 (*Pseudomonas putida* + *Acinetobacter calcoaceticus*). The highest impact on number of fruits (13.9% increase) was observed for ZE-12+13. The application of ZE-2 increased plant fresh weight by 8.8%, whereas ZE-7+13 caused a 1.9% increase. The other treatemnts did not significantly affect plant fresh weight. The highest effect on plant dry weight was observed for ZE-7+12, while ZE-13 and ZE-12+13 increased root dry weight by 15.9%, ZE-7+12 by 15.4%, ZE-7+12+13 by 9.5%, ZE-7+13 by 8.1%, ZE-2 by 6.9%, and ZE-5 by 4.7%. The most increase (9.3%) in root fresh weight was recorded for ZE-13 (*Acinetobacter calcoaceticus*) (Figure 1).

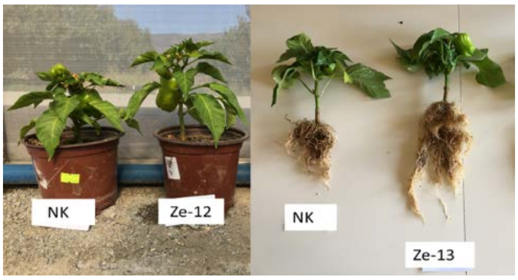

Figure 1. Images from pot experiments.

3.2. Field trials

The highest increase in plant height (12.3%) was observed with the application of ZE-12. Root length was improverd by 11.8% with the application of ZE-7+12 followed by ZE-7 and ZE-12 with 8.1% and 5.9% increase, respectively (Figure 2). The highest increase in stem diameter (16.07%) was observed with the application of ZE-13. Similarly, the highest increase in number of fruits (40.5%) was noted for ZE-12+13. In the same way, ZE-12 application caused 37.2% increase in plant fresh weight. Similarly, ZE-12 application increased plant dry weight by 30.8%.

Root fresh weight was improved by 29.2% with the application of ZE-12. Finally, ZE-7+12 increased root dry weight bu 32.4%, which was significantly different from the control group (Table 4).

Figure 2 Images from the field trials.

Generally, non-significant differences were observed among the treatemnts for evaluated plant traits in pot and field experiments. Nevertheless, root dry weight was statistically significantly different from the control in the field trial. Similar findings were reported by Shrestha et al. (2014), where lactic acid bacteria did not show a significant effect on plant growth in either greenhouse or field studies. While some treatments had negative effects in the pot experiment, these effects were not observed in the field study. This difference may be attributed to several factors, including soil characteristics that support plant growth, nutrient composition of the soil, root colonization, environmental parameters, competition, the production of antagonistic metabolites, and changes in climate conditions (such as temperature and humidity).

Although statistically non-significant differences was observed between the bacterial treatmens and control group for plant growth traits (i.e., plant height, stem diameter, fruit number, plant fresh weight, plant dry weight, root fresh weight, and root dry weight) exhibited some improvement in the field trial. Previous studies have reported that *Pseudomonas putida* increases siderophore production, *Bacillus cereus* degridates phosphate, and *Acinetobacter calcoaceticus* has properties like indole acetic acid production, phosphate reduction, and nitrogen fixation (Santoyo et al., 2012; Kang et al., 2012; Felipe et al., 2021). Furthermore, Pseudomonas and Bacillus species are known to synthesize auxins, multiply rapidly, produce antibiotics, and bacteriotoxins. They also activate systemic resistance and enhance secondary metabolite production, which could explain the positive effects observed in the pepper plants in this study.

A similar study on peanuts reported that *Bacillus* spp. and *Pseudomonas* spp. (specifically *Bacillus velezensis* strains RI3 and SC6, and *Pseudomonas psychrophila* strain P10) applied as PGPR improved plant biomass by 12-18%. This increase was attributed to higher levels of auxins (22%), gibberellins (23%), and cytokinins (27%) (Bigatton et al., 2024). This supports the idea that the positive growth effects in pepper plants could be due to the similar mechanisms exhibited by the bacterial strains used in the current study. Khodabin et al. (2023) investigated the effects of plant growth-promoting bacteria such as *Bacillus subtilis, Azospirillum lipoferum, Azotobacter chroococcum, Enterobacter cloacae*, and *Pseudomonas putida* on soil properties, nutrient uptake, and growth of bell peppers, chemical and biological properties of the soil, NPK uptake, growth, and yield characteristics. It was observed that these bacteria increased the uptake of total nitrogen, phosphorus, and potassium in the soil. The highest nitrogen content in the soil (0.44%), nitrogen uptake (28.8 g/m^2), and shoot dry weight (0.565 g/m^2) were noted for *Azotobacter chroococcum* application. The highest rhizospheric microbial population (7.6×10^6 cfu/g^{-1}) and R/S ratio of 47.9 were recorded with *Enterobacter cloacae*, and this treatment also resulted in higher yield (18.8 kg/m^2) and fruit number (65/8/m^2) (Khodabin et al., 2023). These bacteria were suggested to be used as bio-fertilizers.

In the current study, *E. cloacae* strain (ZE-2) increased number of fruits by 5.5% and plant fresh weight by 8.8% in pot experiment, while *P. putida* increased number of fruit by 5.5%. Khodabin et al. (2023) reported that *P. putida* increased number of fruits by 34% and plant fresh weight by 37.2% in the field tials. These findings suggest that beneficial bacteria can enhance plant growth and yield, which is consistent with the results of this study. The similarity between the findings of current study and previous studies further supports the potential use of these bacteria as growth-promoting agents in pepper cultivation.

Table 3. Effect of bacterial isolates on plant growth in healthy pepper plants (Pot study)

App.	Plant Height		Root Length		Stem Diameter		Fruit Number		Plant Fresh Weight		Plant Dry Weight		Root Fresh Weight		Root Dry Weight	
	Av. (cm)	% Effect	Av. (cm)	% Effect	Av. (cm)	% Effect	Av. piece	% Effect	Av. (cm)	% Effect	Av. (cm)	% Effect	Av. (cm)	% Effect	Av. piece	% Effect
NC	17.2^{a}	0	22.3^{a}	0	2.6^{a}	0	3.4^{a}	0	21.0^{a}	0	2.6^{a}	0	30.9^{a}	0	2.9^{a}	
ZE-2	17.1^{a}	-0.6	22.1^{a}	-1.1	2.8^{a}	5.4	3.6^{a}	5.5	23.1^{a}	8.8	2.5^{a}	-3.6	30.0^{a}	-2.6	3.1^{a}	6.9
ZE-5	17.6^{a}	2.5	22.2^{a}	-0.3	2.7^{a}	1.5	3.6^{a}	4.2	18.3^{a}	-14.9	2.6^{a}	1.2	30.0^{a}	-3.2	2.9^{a}	4.7
ZE-7	16.5^{a}	-4.4	20.2^{a}	-0.3	2.7^{a}	3.6	2.9^{a}	-17.2	20.2^{a}	-3.9	2.2^{a}	-15.8	25.6^{a}	-21.2	2.7^{a}	-4.4
ZE-8	15.3^{a}	-12.6	21.4^{a}	-4.05	2.8^{a}	5.4	3.4^{a}	-1.5	16.0^{a}	-31.2	2.1^{a}	-23.6	24.8^{a}	-25	2.3^{a}	-21.7
ZE-12	17.8^{a}	3.9	20.8^{a}	-7.05	2.7^{a}	2.2	3.6^{a}	5.5	16.1^{a}	-30.7	2.2^{a}	-15.3	30.4^{a}	-1.8	2.8^{a}	-2.1
ZE-13	17.1^{a}	-0.2	22.5^{a}	0.8	2.8^{a}	6.4	3.6^{a}	4.2	16.4^{a}	-28.7	2.5^{a}	-2.8	34.2^{a}	9.3	3.4^{a}	15.9
ZE-7+12	20.3^{a}	15.2	24.0^{a}	7.2	2.7^{a}	4	3.8^{a}	10.5	20.4^{a}	-3.1	3.1^{a}	16.3	32.3^{a}	4.02	3.4^{a}	15.4
ZE-7+13	19.3^{a}	10.8	23.4^{a}	4.6	2.8^{a}	7.7	3.9^{a}	12.8	21.5^{a}	1.9	2.9^{a}	11.7	30.2^{a}	-2.61	3.1^{a}	8.1
ZE-12+13	18.5^{a}	7.03	22.6^{a}	1.1	2.9^{a}	10.2	3.9^{a}	13.9	19.2^{a}	-9.5	2.9^{a}	10.8	31.8^{a}	2.4	3.4^{a}	15.9
ZE-7+12+13	17.1^{a}	-0.3	21.3^{a}	0	2.8^{a}	7.7	3.7^{a}	6.8	16.9^{a}	-24.3	2.7^{a}	7.2	28.1^{a}	-10.2	3.2^{a}	9.5

*The difference between values with the same letter in the same column is statistically non-significant. (p>0.05). (ZE-2: *Enterobacter cloacae*, ZE-5: *Enterobacter aerogenes*, ZE-7: *Bacillus cereus*, ZE-8: *Microbacterium testaceum*, ZE-12: *Pseudomonas putida*, ZE-13: *Acinetobacter calcoaceticus*).

Table 4. Effect of bacterial isolates on plant growth in healthy pepper plants (Field study)

App.	Plant Height		Root Length		Stem Diameter		Fruit Number		Plant Fresh Weight		Plant Dry Weight		Root Fresh Weight		Root Dry Weight	
	Av. (cm)	% Effect	Av. (cm)	% Effect	Av. (cm)	% Effect	Av. piece	% Effect	Av. (cm)	% Effect	Av. (cm)	% Effect	Av. (cm)	% Effect	Av. piece	% Effect
NC	61.2^{a}	0	21.1^{a}	0	4.9^{a}	0	11.5^{a}	0	283.6^{a}	0	64.3^{a}	0	32.3^{a}	0	8.1^{a}	0
ZE-7	69.2^{a}	11.5	22.9^{a}	8.1	5.8^{a}	14.6	11.9^{a}	34	426.2^{a}	33.5	89.9^{a}	28.5	42.9^{a}	24.8	11.2^{ab}	27.5
ZE-12	69.8^{a}	12.3	22.5^{a}	5.9	5.9^{a}	16.3	17.4^{a}	34	451.8^{a}	37.2	92.9^{a}	30.8	45.6^{a}	29.2	11.6^{ab}	29.5
ZE-13	65.7^{a}	6.9	21.5^{a}	1.9	5.9^{a}	16.7	16.7^{a}	31.2	422.8^{a}	32.9	89.0^{a}	27.8	44.5^{a}	27.4	10.9^{ab}	25.7
ZE-7+12	68.8^{a}	11.1	23.9^{a}	11.8	5.8^{a}	14.9	13.9^{a}	17.3	407.5^{a}	30.4	84.7^{a}	24.1	45.2^{a}	28.6	12.0^{b}	32.4
ZE-7+13	68.5^{a}	10.7	22.2^{a}	4.95	5.7^{a}	14.1	17.0^{a}	32.6	419.9^{a}	32.5	88.4^{a}	27.3	39.8^{a}	18.8	10.0^{ab}	18.9
ZE-12+13	64.5^{a}	5.1	22.5^{a}	5.9	5.4^{a}	8.0	19.3^{a}	40.5	375.2^{a}	24.4	76.0^{a}	15.4	33.4^{a}	3.23	8.6^{ab}	5.02
ZE-7+12+13	64.9^{a}	5.8	23.0^{a}	8.3	5.5^{a}	9.5	18.7^{a}	38.6	373.4^{a}	24.1	87.5^{a}	26.5	41.9^{a}	22.9	10.4^{ab}	22.1

*The difference between values with the same letter in the same column is statistically non-significant. (p>0.05). (ZE-2:*Enterobacter cloacae,* ZE-5:*Enterobacter aerogenes,* ZE-7:*Bacillus cereus,* ZE-8:*Microbacterium testaceum,* ZE-12: *Pseudomonas putida,* ZE-13*: Acinetobacter calcoaceticus)*

4. Conclusion

The effects of PGPR (Plant Growth-Promoting Rhizobacteria) applications on growth traits of pepper plants (plant height, root length, stem diameter, number of fruits, plant fresh and dry weight, and root fresh and dry weight) remained non-significant compared to the negative control. However, plant growth traits generally showed positive responses to the PGPR applications in both pot and field trials.

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Conflict of interest

The authors declare no conflicts of interest.

Authorship contribution statement

Z.K: Writing-Original draft preparation, conducting the experiment, taking observations and measurements reviewing and editing. S.B: Conducting the experiment, taking observations and measurements, reviewing and editing. Y.Y: Planning and conducting the experiment, performing statistical analyses, Reviewing and Editing. M.M: Planning and conducting the experiment, reviewing and editing.

References

Belgüzar, S., Ciner, I., Eroglu, Z., & Yanar, Y., (2021). Effects Of Rhızobacterıa On Tomato Bacterıal Cancer And Wılt Dısease. Feb *Fresenius Environmental Bulletin*, 1075.

Bigatton, E. D., Ayoub, I., Palmero, F., Castillejo, M. Á., Vázquez, C., Lucini, E. I., & Haro, R. J. (2024). Plant-growth promoting rhizobacteria on peanuts: Effects on yield determination, growth rates, and radiation use efficiency in field trials in Argentina. *European Journal of Agronomy*, 154, 127113.

Felipe V., Bianco .MI., Terrestre M., Mielnichuk N., Romero A.M., & Yaryura P.M., (2021). Biocontrol of tomato bacterial spot by novel Bacillus and Pseudomonas strains, , *Eur J Plant Pathol* 160, 935–948, https://doi.org/10.1007/s10658-021-02297-6

Fira D., Dimkić I., Berić T., Lozo J., & Stanković S., (2018). Biological control of plant pathogens by Bacillus species, *Journal of Biotechnology* 285, 44–55

Hardoim, P. R., van Overbeek, L. S. & Elsas, J. D. (2008) Properties of bacterial endophytes and their proposed role in plant growth. Trends Microbiol. 16, 463–471

Kang, S. H., Soo Choh., Cheong H., Mınryu C., Kım J. F. & Park S.H. (2007), Two bacterial entophytes eliciting both plant growth promotion and plant defense on pepper (*Capsicum annuum* L.), J. *Microbiol. Biotechnol*., 17(1), 96–103

Kang, S.M., Khan, A.L., Humayun, M., Shinwari, Z. K., Kim, Y.H., Joo G.J., & Lee, I.J. (2012). Acinetobacter calcoaceticus ameliorated plant growth and influenced gibberellins and functional biochemicals. *Pak. J. Bot*., 44(1), 365-372

Kayaaslan, Z. (2021). Tokat ili biber üretim alanlarında bakteriyel leke hastalığı etmeni (*Xanthomonas euvesicatoria*)'nin tanılanması, epidemiyolojisi ve biyolojik mücadelesi. Doktora Tezi, Tokat Gaziosmanpaşa Üniversitesi, Lisansüstü Eğitim Enstitüsü, Tokat, Türkiye.

Khodabin, M., Soudaei Mashaei, S., Barzegar, R., & Ghasemi Ghahsare, M. (2023). Effect of plant growth-promoting rhizobacteria inoculation on soil characteristics, nutrients uptake and growth of bell pepper (*Capsicum annum* L.). *Iranian Journal of Soil and Water Research*, 54(1), 1-13.

Kloepper, J. W., R. M. Zablotowicz, E. M. Tipping, & R. Lifshitz. (1991). Plant growth promoting mediated by bacterial rhizosphere colonizers. The Rhizosphere and Plant Growth, D. L. Keister and P. B. Cregan eds. Kluwer Academic Publishers, Netherlands. 315-326

Mirik M, Aysan Y. & Cinar O. (2008). Biological control of bacterial spot disease of pepper with *Bacillus* strains. *Turk J Agri For* 32, 381–390

Santoyo, G., Orozco-Mosqueda, M. D., & Govindappa, M. (2012). Mechanisms of biocontrol and plant growth-promoting activity in soil bacterial species of *Bacillus* and *Pseudomonas*: a review.*Biocontrol Sci. Technol.* 22, 855–872. https://doi.org/10.1016/j.micres.2008.08.007

Shrestha A, Kim BS, & Parka DH, (2014). Biological control of bacterial spot disease and plant growth-promoting effects of lactic acid bacteria on pepper. *Biocontrol Sci Tech* 24(7):763–779. https://doi.org/10.1080/09583157.2014.894495

Siddiqui, Z.A. (2005). PGPR: prospective biocontrol agents of plant pathogens. In: Siddiqui ZA (eds) PGPR: biocontrol and biofertilization, Springer, Dordrecht https://doi.org/10.1007/1-4020-4152-7_4

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Estimation of Turkey hazelnut export quantity and prices with ARIMA model

Kaan KAPLAN[1]*, Adnan ÇİÇEK[1]

[1]Tokat Gaziosmanpaşa University, Faculty of Agriculture, Department of Agricultural Economics, Tokat, Türkiye

***Corresponding author e-mail:** kaan.kaplan@gop.edu.tr

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Abstract: Hazelnut is of strategic importance for Turkey and is a product subject to international trade. Turkey, which realizes 64% of the world hazelnut production, is also the country that exports the most. It is important to estimate the future hazelnut price, export amount and income from exports to maintain the country's position. Hazelnut export unit price ($/ton), hazelnut export quantity (tons) and hazelnut export value ($) variables in Turkey between 1961 and 2023 were used and forecasted with ARIMA model for 2024, 2025 and 2026. Statistical error evaluation criteria such as mean absolute percentage error (MAPE), mean absolute error (MAE), root mean square error (RMSE), normalized Bayesian information criterion (BIC) etc. were used to test the validity of the ARIMA model, which indicated that the model was reliable. In addition, the augmented Dickey-Fuller test (ADF) and Phillips-Perron test (PP) unit root tests were applied to determine the stationarity levels of the series. The series was stationarity at different levels and the Ljung-Box significance levels of the series were appropriate for the models. It is predicted that export unit price and hazelnut export value will follow an increasing trend in the next three years, while hazelnut export quantity will follow a fluctuating course. In addition, it can be said that the export quantity will continue to follow a fluctuating course over the years with the effect of periodicity in production, while the export unit price and export value will continue its upward trend in a fluctuating manner with the effect of the crisis experienced after 2005.

Keywords: ARIMA model, hazelnut price, hazelnut exports, Türkiye

Türkiye fındık ihracat miktarı ve fiyatlarının ARIMA modeli ile tahmini

Öz: Fındık Türkiye için stratejik öneme sahip olup, uluslararası ticarete konu olan bir üründür. Dünya fındık üretiminin %64'ünü gerçekleştiren Türkiye, aynı zamanda en fazla ihracat yapan ülkedir. Ülkenin bu konumunu sürdürebilmesi için geleceğe ilişkin fındık fiyatı, ihracat miktarı ve ihracattan elde edilen gelirin bilinmesi önemlidir. Çalışmada 1961-2023 yılları arasındaki Türkiye fındık ihracat birim fiyatı ($/ton), Türkiye fındık ihracat miktarı (ton) ve Türkiye fındık ihracat değeri ($) değişkenleri kullanılmış ve Türkiye için 2024, 2025 ve 2026 yıllarına dair ARIMA modeli ile tahminler yapılmıştır. ARIMA Modelinin geçerliliğini sınamak amacıyla MAPE, MAE, RMSE, Normalize BIC vb. istatistiki hata değerlendirme ölçütleri yapılmış ve modelin güvenilir olduğu tespit edilmiştir. Ayrıca serilerin durağanlık seviyelerini tespit etmek amacıyla ADF ve PP birim kök testleri uygulanmıştır. Seriler farklı seviyelerde durağanlık göstermekte ve serilerin Ljung-Box anlamlılık düzeyleri modeller için uygundur. Çalışma sonuçlarına göre Türkiye ihracat birim fiyatı ve Türkiye fındık ihracat değerinin gelecek üç yılda artış trendinde olacağı, Türkiye fındık ihracat miktarının ise dalgalı bir seyir izleyeceği tespit edilmiştir. Ayrıca ihracat miktarının üretimdeki periyodisite etkisi ile yıllar itibariyle dalgalı bir seyir izlemeye devam edeceği, ihracat birim fiyatının ve ihracat değerinin 2005 yılından sonra yaşanan krizin etkisi ile artış trendini dalgalı şekilde sürdüreceği söylenebilir. Fiyatlardaki bu oynaklığın dikkate alınarak uygun politikaların izlenmesi ve üreticilerin fiyat oynaklığından korunması önem arz etmektedir.

Anahtar kelimeler: ARIMA modeli, fındık fiyatı, fındık ihracatı, Türkiye

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1. Introduction

Hazelnuts are a strategically important product for Turkey. Turkey accounts for 64.0% of global hazelnut production and 57.4% of global hazelnut exports, ranking the country first worldwide in both production and export. Hazelnuts and hazelnut products are among Turkey's leading agricultural export commodities, constituting 9% of the country's annual agricultural exports and 2% of its total exports (Anonymous, 2024). Hazelnuts serve as a raw material in various industries, including snacks, confectionery, chocolate, halvah, and baking, which further underscores their strategic significance in terms of imports and exports (Kırsahanoğlu, 2022). Consequently, the future trajectory of hazelnut prices and export volumes is of critical importance for Turkey, which holds the top position in global exports. Although Turkey ranks first in the world in hazelnut production and export, the entry of countries such as Italy, Chile, Azerbaijan, and Georgia into the market in recent years has affected Turkey's share in this sector. Chile increased its hazelnut production from 180 tons in the 1990s to 62 thousand tons by 2022, and Azerbaijan increased its hazelnut production from 7 to 8 thousand tons in the 1990s to 72 thousand tons in 2022. These countries are gaining a more prominent position in hazelnut production, with South American nations, particularly Chile, increasing their output thanks to favorable climatic conditions. Moreover, countries like Georgia, Azerbaijan, Iran, and some Middle Eastern nations are gaining a competitive advantage due to low labor costs. These developments highlight the need for further economic analysis regarding how Turkey's hazelnut production and exports might be impacted (Aydoğan & Meral, 2024). Turkey's production of 765,000 tons (64% of global output) clearly demonstrates the country's dominant position in this sector. Italy and Azerbaijan follow as the second and third largest producers, with 98,670 tons and 72,105 tons, respectively. These top three producers are followed by the United States, Chile, Georgia, China, Iran, France, and Poland. The total global hazelnut production amounts to 1,195,732 tons. Turkey's contribution to 64% of global production is driven by both domestic market dynamics and international competitive conditions, providing a significant indicator of how global production strategies are evolving. The entry of South American countries and China into hazelnut production exemplifies this trend.

Table 1. The countries producing the most hazelnuts in the World (2022).

Countries	Import Quantity (tonnes)	Countries	Import Value ($)
Germany	69 493	Germany	484 964 426
Italy	58 163	Italy	375 986 506
France	23 068	France	152 327 672
Canada	17 419	Canada	121 868 984
Switzerland	9 627	Brazil	73 864 055
Brazil	7 949	Switzerland	64 181 739
Holland	5 469	Poland	45 011 606
Poland	5 211	Holland	37 716 626
Austria	3 320	Austria	23 154 370
Belgium	2 838	Belgium	20 476 157
Others	22 092	Others	232 770 897
World	224 648	World	1 632 323 038

Table 2. Top ten countries in world export quantity and export value (2022).

Countries	Export Quantity (tonnes)	Countries	Export Value ($)
Turkey	153 678	Turkey	995 330 274
Holland	26 059	Chile	231 925 106
Azerbaijan	21 947	Italy	185 781 832
Italy	21 617	Azerbaijan	119 555 427
Georgia	13 167	USA	99 078 251
USA	12 552	Georgia	74 188 441
Germany	7 542	Germany	59 352 976
Czechia	1 005	Holland	43 885 353
Spain	943	Czechia	6 955 466
Armenia	905	Spain	6 687 167
Others	8 154	Others	29 627 236
World	267 569	World	1 852 367 529

In 2022, Turkey ranked first globally in hazelnut exports with an export volume of 153,678 tons. The Netherlands and Germany, despite having no domestic production, are among the top ten countries in export volume and value due to their role as re-export hubs. Globally, the total hazelnut export volume reached 267,596 tons, with an export value of $1,852,367,529.

Germany ranks first globally in both hazelnut import volume and export volume. Germany is followed by Italy, France, Canada, and Switzerland. Except for Italy and France, the other countries do not hold a significant share in hazelnut production, yet their prominent role in imports indicates their re-export activities and a more active involvement in the hazelnut market. Re-export is a form of international trade in which a country exports previously imported goods without changing them. With the re-export method, the above-mentioned countries can determine the market prices for hazelnuts themselves. For this reason, the international market prices of hazelnuts are mostly determined in European stock exchanges. Globally, the total hazelnut import volume amounted to 224,648 tons, with an import value of $1,632,323,038.

Numerous studies have been conducted on hazelnut prices. Özer and Yavuz (2014) used the Box-Jenkins model to forecast hazelnut prices. Şeyranlıoğlu (2022) detailed the relationship between hazelnut prices and exchange rates. Bayyurt and Deveci Kocakoç (2023) employed the NARX technique of artificial neural networks to predict hazelnut production volumes, while Kara (2024) attempted to forecast hazelnut prices in Turkey using artificial neural networks. Bülbül and Tanrıvermiş (1999) examined traditional and organic hazelnut production and export potential in Turkey, linking stock increases to production growth and low domestic and foreign demand. Based on their findings, they proposed recommendations for restructuring hazelnut production and marketing policies. Sarımeşeli and Aydoğmuş (2000) aimed to develop policy alternatives for the global hazelnut market using data from the 1967–1985 period, applying a quadratic programming model. Their results assessed the potential impacts of alternative policies on producer welfare in Turkey.

Table 3. Top ten countries in world import quantity and import value (2022).

Countries	Import Quantity (tonnes)	Countries	Import Value ($)
Germany	69 493	Germany	484 964 426
Italy	58 163	Italy	375 986 506
France	23 068	France	152 327 672
Canada	17 419	Canada	121 868 984
Switzerland	9 627	Brazil	73 864 055
Brazil	7 949	Switzerland	64 181 739
Holland	5 469	Poland	45 011 606
Poland	5 211	Holland	37 716 626
Austria	3 320	Austria	23 154 370
Belgium	2 838	Belgium	20 476 157
Others	22 092	Others	232 770 897
World	224 648	World	1 632 323 038

Reference: FAOSTAT, 2024

Yavuz et al. (2004) carried out a study aiming to provide alternative policies to solve the problems of hazelnut sector in Turkey. In this study, a model was developed for the current situation and problems of the hazelnut sector and applied using the least squares method. Bayramoğlu and Gündoğmuş (2007) analyzed the Dynamics of the World hazelnut market and investigated the effect of Turkey on price formation and price determinants in global markets. Using data for the period 1970-2004, they analyzed the variance decomposition, impulse-response function and Granger Causality tests. The findings of the analyses revealed that the position of countries own currencies against the dollar, the amount of hazelnut production in Turkey and the price of Fındık Tarım Satış Kooperatifleri Birliği (FİKSOBİRLİK) play a determinant role in determining the prices in the world hazelnut market. Usta (2007) examined the distribution of Turkey's hazelnut exports by market and product groups between 1996 and 2005. The findings revealed that the market structure of Turkey's hazelnut exports remained unchanged during this period. The study concluded with a recommendation to preserve surplus hazelnuts under suitable storage conditions and to take new steps toward product development. Erdal and Uzunöz (2008) investigated the causal relationship between hazelnut prices and exchange rates. They analyzed the relationship between Turkey’s hazelnut export prices, European stock market prices, and exchange rates for the period 1995–2007, applying Johansen cointegration and Granger causality tests. The results indicated a long-term relationship among these variables. Based on the findings, it was recommended that Turkey’s hazelnut export prices be made less susceptible to exchange rate uncertainties. Hatırlı et al. (2008) analyzed the price pass-through of hazelnuts from Turkey to Germany. Using monthly data from 1996–2006, the study applied a double-logarithmic model and the GARCH approach. The results attributed to the lack of price pass-through to hazelnuts being a storable product. Akal (2009) examined Turkey's shelled hazelnut exports using simple econometric methods and autoregressive moving averages. Models based on natural logarithms were developed, revealing that the exchange rate elasticity of shelled hazelnut exports was inelastic, while the export revenue elasticity of shelled hazelnut export volumes was elastic. The study predicted an increase in shelled hazelnut export revenues based on these models. Parlaktuna (2009) conducted an empirical study focusing on Turkey's hazelnut exports from 1980 to 2007. The analysis employed a two-stage least squares method and found no strong substitution relationship between hazelnuts and almonds. Additionally, production and stock levels were shown to have a negative impact on export prices. The study concluded that export prices are determined by supply dynamics in the market. Akseki (2012) analyzed price formation in the global hazelnut market and proposed alternative policies for Turkey. The study employed time series and panel data methods for econometric analysis. The results indicated that the purchasing prices set by FİSKOBİRLİK had a significant upward impact on global hazelnut prices. Uçar (2014) examined Turkey's hazelnut export demand during the 2001–2011 period, focusing on data from countries such as Germany, France, Belgium, Poland, Switzerland, Italy, and the Netherlands. Panel data analysis was applied, and the fixed-effects model was identified as the most appropriate approach for the analysis. The findings reveal that the export demand model satisfies the self-interest assumption but not the equal diffusion assumption. Çabaş (2017) examined the effects of hazelnut exports on foreign trade in the post-1990 period, focusing on the Sakarya province. The empirical analysis utilized data from 2004 to 2016 to explore causal relationships between hazelnut exports, Turkey's and Sakarya's GDP, and foreign trade. The study employed the Toda-Yamamoto causality test along with ADF, PP, and Vogelsang-Perron structural break unit root tests. The results revealed unidirectional causality from Turkey's total exports to Sakarya's hazelnut exports and from Sakarya's GDP to hazelnut exports, as well as a unidirectional causality relationship involving exchange rates. Kılıç and Turhan (2020) attempted to explain Turkey's hazelnut exports using the Box-Jenkins method and forecasted future export volumes. The study analyzed hazelnut export data from 1961 to 2018, employing the ARIMA model for projections. According to the findings, Turkey's hazelnut export volume was predicted to reach 162,000 tons in 2019 and 176,000 tons in 2023. Merdan (2024) investigated the factors influencing Turkey's hazelnut export demand using the ARIMA model. The study assessed the impacts of global hazelnut imports, unit prices, and Turkey's export unit prices from 2001 to 2021. The findings indicated that these variables were not significant determinants of Turkey's hazelnut exports. However, the study revealed that global hazelnut export volumes positively influenced Turkey's hazelnut exports.

Despite Turkey being the world's largest hazelnut producer and exporter, the dominance of countries like Germany and the Netherlands in the market due to re-export activities, as well as the increasing production in countries such as Chile, China, and the United States, make the future of Turkey's hazelnut prices and export volumes highly significant. The presence of hazelnut exchanges in Germany and Italy, and their role in determining global hazelnut prices, contributes to Turkey's hazelnut prices not being the primary determinant, despite its leading position in global production. The study examines the future projections of Turkey's hazelnut export unit prices, export value, and export volumes using the ARIMA model. The aim of the study is to analyze how Turkey's hazelnut prices will evolve in the future, and whether new entrants in the hazelnut export market will lead to any changes in Turkey's export volume.

2. Materials and Methods

The main material of the study consists of data obtained from FAOSTAT and UN Comtrade. Turkey hazelnut export quantity (tons), Turkey hazelnut export value ($) and Turkey hazelnut export unit price ($) data for the years 1961-2023 were used. There is no missing data in the series and no data transformation was performed.

The Augmented Dickey-Fuller (ADF) test developed by Dickey and Fuller (1981) and the Phillips-Perron (PP) test developed by Phillips and Perron (1988) are used to determine series trend to determine the stationarity of the series before constructing the ARIMA model.

The ARIMA model can achieve high accuracy rates in short-term forecasts (Akdağ, 2016). For this reason, forecasting is limited to three years to avoid a high margin of error in long-term forecasts. The most striking feature of SPSS in time series analysis is its ability to automatically determine forecasting techniques.

ARIMA is a widely used method in time series analysis and continues to be popular today (Akpınar, 2020). This method makes it possible to predict future trends by examining past data (Kutlar, 2006). SPSS is a frequently preferred software for modeling and data analysis and this software offers the opportunity to automate model an parameter selection processes, to check for seasonality, interruptions and missing data in the data set, and to display goodness-of-fit measures (R^2, RMSE, MAPE, MAE, BIC) (Eşidir & Metin, 2021).The estimated ARIMA models are evaluated based on criteria such as significance of parameter coefficients, constant R-Square, Normalized Bayes Information Criterion (BIC), Root Mean Square Error (RMSE), Mean Absolute Error (MAE) and Mean Absolute Percentage Eror (MAPE). In line with these criteria, the model with the lowest BIC, RMSE, MAE and MAPE values and the highest Constant R^2 value is considered the most appropriate model (Oni & Akanle, 2018; Çelik, 2019). To Show that a model has a successful forecasting performance, the MAPE value is expected to be below 10% and the p-value of the Ljung-Box Q test is expected to be greater than 5%. In addition, the lower the Normalized Bayes Information Criterion (BIC), the better the fit of the model to the series (Pankratz, 1983; Oğhan, 2010; Pektaş, 2013).

ARIMA Model is a combination of AR and MA models. The AR model uses observations from previous time periods to predict the value in the next time period. There may be a relationship between values in different periods. This relationship is called inter-variable correlation if the relationship changes in the opposite direction and a positive correlation if it changes in the same direction. Statistics-based metrics are used to calculate correlation. The AR (p) notation is expressed by equation (1) below.

$$X_t = c + \sum_{i=1}^{p} \varphi_i \, X_{t-1} + \varepsilon_t \qquad (1)$$

In equation (1), c is a constant coefficient. The time series is denoted by X_t and the integer index of the time series is denoted by t. The parameter values of the AR model are denoted by φ_i . P is the number of lags of the model and ε_t is the constant variance error term with zero mean. The MA model is called a Rolling or moving average. For use in data analysis, different subsets, if any, calculate the average of other subsets (Kaya et al., 2020).

$$X_t = \mu + \varepsilon_t \sum_{i=1}^{q} \theta_i \, \varepsilon_{t-i} \qquad (2)$$

μ in equation (2) denotes the mean of the series in the model. The value of the moving average is denoted by θ_i and the order of the average is denoted by q. X_t denotes the time series. The error terms are denoted by ε_t and ε_{t-i} (Kaya et al., 2020). ARIMA both linearly models the next step from the previous steps and combines AR and MA models. In addition, it makes the sequence stationary by combining the preprocessing step. This precess is called integration and is expressed by the following equation (Kaya et al., 2020).

$$X_t = \frac{(1+\sum_{i=1}^{p} \theta_i L^i)\varepsilon_t}{(1-\sum_{i=1}^{p} \emptyset_i L^i)(1-L)^d} \qquad (3)$$

The lag operatör used in equation (3) is denoted by L. The Parameter value in the autoregressive model is denoted by Ø, while the parameters of the moving average model are denoted by θ_i. X_t represents the time series, while the error terms are denoted by ε_t (Kaya et al., 2020). The ARIMA (p,d,q) model uses three main variables as input parameters. Among these variables, p represents the number of lags, d represents the degree of differencing and q represents the moving average window size. However, first the time series must be stationary, in which case d=1 is chosen. One of these methods is to examine the autocorrelation function (ACF) and partial autocorrelation function (PACF) graphs. These plots are used to determine the number of AR and MA terms. The also provide information on trend and seasonality. The ACF shows the value of autocorrelation in a series and is important for understanding the relationship between past and current values. The ACF is known as the full autocorrelation function because it analyzes components such as trend, seasonality and noise. In non-stationary time series, the ACF plat shows a decreasing trend over time. The PACF shows the time-varying correlations between two data points and is used to determine the optimal number of terms in the AR model. This number of terms is also a parameter that determines the degree of the model (Akçay, H., Yıltaş-Kaplan, D., 2024).

In the study, the ARIMA model was used for the forecasts of all variables and annual data and three-year (2024, 2025 and 2026) forecast values were analyzed.

3. Results and Discussion

The data set in the study consists of hazelnut export unit price, export quantity and export value. The names of the variables are coded for ease of analysis. Turkey Hazelnut Export Unit Price is coded as THEUP, Turkey Export Quantity (tons) as TEQ and Turkey Export Value ($) as TEV. In the study, Augmented Dickey-Fuller Test (ADF) and Phillips-Perron (PP) unit root tests were applied to test the stationarity of the series.

As mentioned in Equation (3), d=1 was chosen to make the series stationary while constructing the ARIMA model. Table 4 presents the ADF and PP unit root tests of the variables.

Table 4 shows that the series are stationary at different levels. Accordingly, while THEUP and TEV variables are non-stationary at level and constant, they are stationary at level and constant trend. The TEQ variable is stationary at both level and first difference. While all the series are stationary in the first difference, only the TEV variable does not Show stationarity in the ADF unit root test in the first difference but shows stationarity in the PP unit root test in the same first difference.

Figure 1 shows the forecast value, upper limit and lower limit of the unit price of hazelnut exports in Turkey. While forming the unit price between 1961-2023, forecasting was made from 2024 onwards. Except for 1979, the export unit price, which has followed a stable course since 1961, showed a significant increase in 2005 and then followed a fluctuatin graph. During this period, FISKOBIRLIK, the cooperative organization of which hazelnut producers are members, was unable to make payments for some of the products purchased in 2005 and 2006 and faced a financial crisis. This led to a sharp increase in hazelnut prices. As a result of the economic and social problems experienced by producers, the Toprak Mahsulleri Ofisi (TMO) decided to purchase surplus hazelnuts on behalf of the state. After this process, which lasted until 2012, hazelnut prices were left to free market conditions again (Özcüre, 2012). Starting in 2005, price fluctuations continued until 2023.

Table 5 presents the ARIMA (1,2,1) model of Turkish hazelnut export unit price and future forecasts. In the tests for the validity of the model, the R^2 value of the model was found to be 0.787. Since the Ljung-Box Q value is greater than 5% (0.085), it is determined that the model is compatible with the data. The mean absolute percentage error (MAPE) value is 16%, which is between 10% and 20%, indicating that the model has a good level. The normalized BIC (Bayes Information Criterion) was 14.287. As a result of all these tests, Turkey's hazelnut export unit price is predicted to be 6 639,20 $/ton ,n 2024, 6 750,67 $/ton in 2025 and 6 859,97 $/ton in 2026. Accordingly, it can be said that Turkey's hazelnut export unit price will continue its upward trend since 2022.

Figure 2 shows the forecast value, upper limit and lower limit of the projection for Turkey's exports (tons). Since 1961, there has been an increase in the amount of exports, but it still follows a fluctuating course with the increase. The most important reason for this fluctuation is the periodicity effect observed in hazelnut production. In Table 6, the ARIMA (1,2,1) model of Turkey's export volume (tons) and future forecasts are given. In the tests for the validity of the model, the R^2 value of the model was found to be 0.644. The Ljung-Box Q value was found to be 0.189 and since it was greater than 5%, it was determined that the model was compatible with the data. The mean absolute percentage error (MAPE) value is 14%, which is between 10% and 20% indicating that the model is good. The normalized BIC (Bayes Information Criterion) is 20,220. As a result of all these tests, Turkey's export volume (tons) is projected to be 162 433 tons in 2024, 157 819 tons in 2025 and 158 039 tons in 2026. It is estimated that the amount of exports is in line with the general course of the series and that after 2024, there will be a decline in 2025 and then increase again.

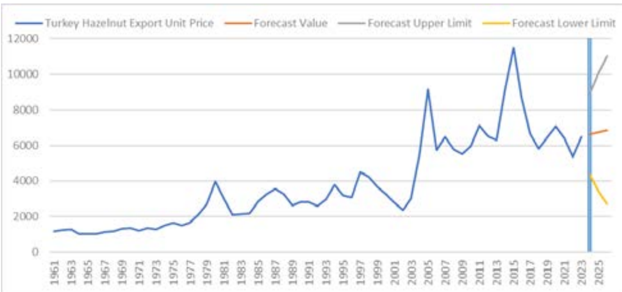

Figure 1. Turkey hazelnut export unit price data and future forecasts

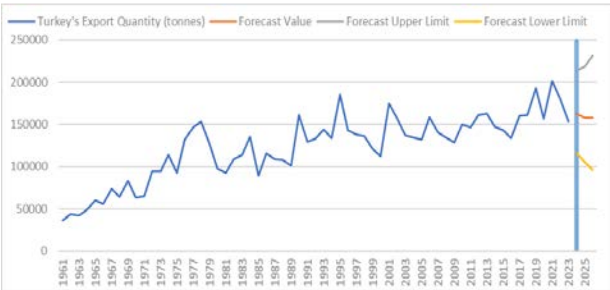

Figure 2. Turkey's export quantity (tonnes) data and future forecasts

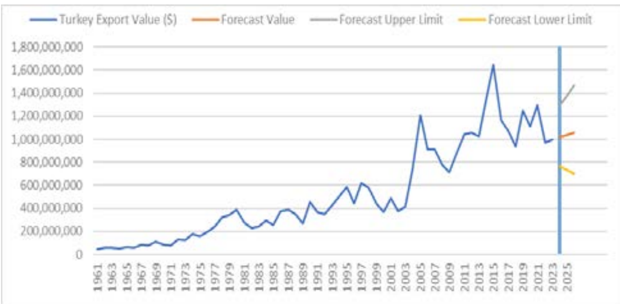

Figure 3. Turkey export value ($) data and future forecasts

Table 4. ADF and PP unit root tests

		Variables	ADF	PP		Variables	ADF	PP
Level	Intercept	THEUP	-1.7852	-1.5881	*1st difference*	THEUP	-7.3379***	-17.0975***
		TEQ	-2.9424**	-2.6908*		TEQ	-11.6752***	-19.7816***
		TEV	-1.4873	-1.2783		TEV	-1.7107	-20.9589***
	Trend and intercept	THEUP	-4.5350***	-3.5704**		THEUP	-7.2721***	-16.8304***
		TEQ	-4.9844***	-4.9844***		TEQ	-11.6352***	-25.9573***
		TEV	-3.9438**	-3.8150**		TEV	-1.2788	-20.5530***

Table 5. ARIMA (1,2,1) results for Turkey hazelnut export unit price

Turkey Hazelnut Price	2024			2025			2026
Forecast Value	6 639.20			6 750.67			6 859.97
Forecast Upper Limit	8 920.38			10 092.99			11 025.65
Forecast Lower Limit	4 358.02			3 408.34			2 694.29
Model	Constant R^2	R^2	RMSE	MAPE	MAE	Normalize BIC	Ljung-Box Q (Sig.)
	0.475	0.787	1144.002	16.322	727.422	14.287	0.082

Table 6. ARIMA (1,2,1) results for export quantity (tonnes)

Export Quantity (tons)	2024			2025			2026
Forecast Value	162 433			157 819			158 039
Forecast Upper Limit	213 600			218 333			231 595
Forecast Lower Limit	116 717			105 001			95 591
Model	Constant R^2	R^2	RMSE	MAPE	MAE	Normalize BIC	Ljung-Box Q (Sig.)
	0.683	0.644	22227.949	14.342	17260.389	20.220	0.189

Table 7. ARIMA (1,1,0) results for export value ($)

Export Value ($)	2024			2025			2026
Forecast Value	1 014 954 574			1 036 040 574			1 056 728 305
Forecast Upper Limit	1 291 938 847			1 374 163 654			1 467 071 244
Forecast Lower Limit	763 859 756			735 122 921			699 179 261
Model	Constant R^2	R^2	RMSE	MAPE	MAE	Normalize BIC	Ljung-Box Q (Sig.)
	0.448	0.936	106623541.8	14.780	77047442.63	37.302	0.510

The timeline of Turkey's export value ($) is given in figure 3. Since 1961, the value of exports has followed a normal course, while in 2005 it increased with an increase similar to the export unit price and it can be said that it fluctuates. Table 7 presents the ARIMA (1,1,0) model of Turkey's export value ($) and future forecasts. For the validity tests of the model, the R^2 value of the model was found to be 0.936. The Ljung-Box Q value was found to be 0.510 and since it was greater than 5%, it was determined that the model was compatible with the data. The mean absolute percentage error (MAPE) value is 14%, which is between 10% and 20%, indicating that the model has a good accuracy level. The normalized BIC (Bayes Information Criterion) is 37,302. As s result of all these tests, Turkey's export amount (tons) is predicted to be 1 014 954 574 USD in 2024, 1 036 040 574 USD in 2025 and 1 059 728 305 USD in 2006. It can be said that the export value will continue the upward trend that it has achieved in 2022 for three years. Even if the amount of hazelnut production and exports fluctuate slightly for the next 3 years, the hazelnut export unit price continues its upward trend. This shows that hazelnut prices are not affected much by small changes in supply and that the stock exchanges are dominant over prices.

4. Conclusion

Hazelnut is a strategic agricultural product for Turkey and has a great importance in terms of both economic and international trade. For this reason, future projections of hazelnut foreign trade are important. Turkey's leading position in the World and the continuation of this position in the coming years in an increasingly competitive environment is important in terms of dominating the market. However, as mentioned before, although Turkey is the leading exporter in the market, it does not have a say in the stock market prices. Projections made with the ARIMA model show that Turkey's hazelnut export unit price will be in an increasing trend between 2024 and 2026. Accordingly, hazelnut export unit price is expected to reach 6 639,20 $/tons in 2024 and 6 859,97 $/tons in 2026. Although the export amount follows a fluctuating course, it is expected to reach 162 433 tons in 224 and 158 039 tons in 2026. Turkey's hazelnut export value will continue to increase in the same period and is estimated to reach 1 059 728 305 USD by 2026. Different policies created over the years, acting with government policy instead of state policy have led to the formation of different problems in hazelnut in different periods. The excess supply caused by the rapid increase in hazelnut areas and the rise in hazelnut prices in 2005 are examples of this. For this reason, it can be said that sudden price changes can be prevented with fixed production planning and need-oriented agricultural policies. This situation causes the hazelnut price to play a more active role especially in European-based stock exchanges. The same care shown to produce hazelnuts should also be applied to the market structure, and hazelnut prices should be organized by the producing country within the framework of free competition conditions through the stock exchanges established in Turkey. These findings show that although Turkey maintains its leading position in the world hazelnut market, it needs to develop more careful strategies against increasing international competition conditions and fluctuations in the domestic market. Turkey should both invest in production technologies and diversify its export markets to ensure sustainable growth in hazelnut production and exports. In addition, measures should be taken against Halyomorpha Halys, which has caused serious damage to hazelnuts in recent years. The pest, which significantly reduces the yield rate in hazelnuts, affects the production of quality hazelnuts, and this problem has the potential to damage the value of hazelnuts produced in Turkey in the international market.

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Conflict of interest

The authors declare no conflicts of interest.

Authorship contribution statement

K.K and A.Ç: The authors declare that they have contributed equally to the article.

References

Akal, M. (2009). Türkiye'nin iç fındık ihracatı tahmini ve öngörü doğruluğu. *Uluslararası Yönetim ve İktisat ve İşletme Dergisi,* 5(10), 77-96.

Akçay, H., & Yıltaş-Kaplan, D. (2024). Zaman serileri tahminleme algoritmaları ile kontör tüketim tahminlemesi ve karşılaştırmalı uygulaması. *Kahramanmaraş Sütçü İmam Üniversitesi Mühendislik Bilimleri Dergisi*, 27(1), 166-189.

Akdağ, R. (2016). Yapay sinir ağları, destek vektör makineleri ve Box-Jenkins yöntemleriyle kentsel içmesuyu talebi tahmini ve karşılaştırmalı analizi. *Business and Economics Research Journal*, 7(1), s. 123-138.

Akpınar, M., & Yumuşak, N. (2020). Günlük temelli orta vadeli şehir doğal gaz talebinin tek değişkenli istatistik teknikleri ile tahmini. *Journal of the Faculty of Engineering and Architecture of Gazi University*, 35(2), s. 725-741.

Akseki, U. (2012). Dünya fındık piyasasında fiyat Oluşumu ve Türkiye için alternatif politikaların belirlenmesi. (Yayımlanmış Doktora Tezi). Ege Üniversitesi Sosyal Bilimler Enstitüsü, İzmir.

Anonim (2024). Trade: Crops and Livestock Products. Food and Agriculture Organization of the United Nations (FAO), Erişim Tarihi: 07.09.2024

Aydoğan, M., & Meral, H. (2024). Fındık üretiminin karlılığı ve fındık işletmelerinin asgari gelir düzeylerinin belirlenmesi. *Türkiye Tarımsal Araştırmalar Dergisi,* 11(1): 71-81.

Bayramoğlu, Z., & Gündoğmuş, E. (2007). Dünya fındık piyasasının analizi. *Gazi Üniversitesi İktisadi ve İdari Bilimler Fakültesi Ekonomik Yaklaşım Dergisi,* 18(65), 71-89.

Bayyurt, D., & Deveci Kocakoç, İ. (2023). Yapay sinir ağları NARX ile Türkiye fındık üretim miktarı tahmini, *Giresun Üniversitesi İktisadi ve İdari Bilimler Dergisi,* 9(1), 15-35.

Bülbül, M., & Tanrıvermiş, H. (1999). Türkiye'de ekolojik ve geleneksel fındık üretiminin ekonomik yapısı ve ihracat potansiyeli. *Karadeniz Bölgesinde Tarımsal Üretim ve Pazarlama Sempozyumu, Samsun: Karadeniz Tarımsal Araştırma Enstitüsü Yayınları, Yılmaz Ofset.*

Çabaş, M. (2017). 1990 sonrası fındık ihracatının Türkiye'nin dış ticareti üzerine etkileri: Sakarya örneği. [Yayımlanmamış Yüksek Lisans Tezi]. Sakarya Üniversitesi Sosyal Bilimler Enstitüsü, Sakarya.

Çelik, Ş. (2019). Modeling and estimation of potato Production in Turkey with time series Analysis. *International Journal of Trend in Research Development*, 6(5), 111-116.

Dickey, D.A., & Fuller, W.A. (1981). Likelihood ratio statistics for autoregressive Time Series with a Unit Root. *Econometrica*, 49 (4): 1057-1072.

Erdal, G., & Uzunöz, M. (2008). Türkiye ve Avrupa fındık fiyatları ve döviz kuru arasındaki nedensellik ilişkisi. *Uludağ Üniversitesi Ziraat Fakültesi Dergisi,* 22(2), 47-56.

Eşidir, K.A., & Metin, S. (2021). arıma yöntemi ile tüketici fiyat endeksi tahmini. *İktisadi ve İdari Bilimler Alanında Uluslararası Araştırmalar Dergisi*. 978-625-7316-68-2.

Food and Agricultural Organization, Faostat (2024). Erişim Linki: https://www.fao.org/faostat/en/#home Erişim Tarihi: 30.08.2024.

Hatırlı, S.A., Öztürk, E., & Aktaş, A.R. (2008). Fındık piyasasında fiyat geçirgenliğinin analizi. *Akdeniz Üniversitesi Ziraat Fakültesi Dergisi,* 21(1), 139-143.

Kaya, U., Akba, F., Medeni, İ.T., & Medeni, T.D. (2020). Bitcoin fiyat değişimlerinin makine öğrenmesi, zaman serileri analizi ve derin öğrenme yöntemleriyle değerlendirilmesi. *Bilişim Teknolojileri Dergisi,* 3(13), 341-355.

Kılıç, T.M., & Turhan, Ş. (2020). Türkiye'de fındık ihracatının box-jenkins yöntemiyle modellenmesi ve ihracat öngörüsü. *IBAD Sosyal Bilimler Dergisi (Milli Mücadele'nin 100. Yılı Özel Sayısı),* 453-461.

Kırsahanoğlu, Ş. (2022). Fındık fiyatını etkileyen faktörlerin VAR modeliyle analizi. *Fındık Ekonomisi*. K.Y. Genç, Y. Mamur Işıkçı & M. Özdemir (Edt.), s. 165-182. Bursa.

Kutlar, A., & Turgut, T. (2006). Türkiye'deki Başlıca Ekonomi Serilerinin ARFIMA modelleri ile tahmini ve öngörülebilirliği. *Kocaeli Üniversitesi Sosyal Bilimler Enstitüsü Dergisi* (11), s. 120-149.

Merdan, K. (2024). Türkiye'de fındık ihracat talebine etki eden faktörlerin ARIMA modeli ile tahmin edilmesi, *Kastamonu Üniversitesi İktisadi ve İdari Bilimler Fakültesi Dergisi*, 26(1), 40-68.

Oğhan, S. (2010). Zaman serisi analiz yöntemlerinin karşılaştırılması. Ege Üniversitesi Fen Bilimleri Enstitüsü. Yüksek lisans tezi.

Oni, O., & Akanle, Y. (2018). Comparison of exponential smoothing models for forecasting cassava production. *International Journal of Scientific Research in Mathematical and Statistical Sciences*, 5(3), 65-68.

Özcüre, G. (2012). Tarım politikasına uyum perspektifinde fiskobirlik ve fındık üreticilerinin ekonomik ve sosyal sorunlarına çözüm arayışları. *Kent Akademisi,* 5(11), 105-128.

Özer, O.O., & Yavuz, G.G. (2014). Box-Jenkins Modeli yardımıyla fındık fiyatlarının tahmini. *XI. Ulusal Tarım Ekonomisi Kongresi*, 3(5).

Pankratz, A. (1983). Forecasting with univariate box-jenkins models: concept and cases. John, Wiley and sons, New YorkIJRDO - *Journal of Agriculture and Research*.(4), (12), 201813.

Parlaktuna, İ. (2009). Türkiye'nin fındık ihracatı analizi: 1980-2007 dönemi Uygulaması. *İktisat, İşletme ve Finans,* 24(277), 61-80.

Pektaş, A.O. (2013). SPSS ile Veri Madenciliği, Dikeyeksen Yayınları, ISBN:978-605-86660-4-7, İstanbul.

Perron, P. (1997). Further evidence on breaking trend functions in macroeconomic variables. *Journal of Econometrics*, 80 (2): 355-385.

Sarımeşeli, M., & Aydoğuş, O. (2000). Dünya fındık piyasasının ekonomik analizi ve türkiye için optimum politikaların saptanması. *Ankara: Tarımsal Ekonomi ve Araştırma Enstitüsü.*

Şeyranlıoğlu, O. (2022). Fındık fiyatları ile döviz kuru arasındaki saklı ilişkinin analizi. *fındık Ekonomisi*. K.Y. Genç, Y. Mamur Işıkçı & M. Özdemir (Edt.), s. 261-278. Bursa: Ekin.

Uçar, Ö. (2014). Türkiye fındık ihracat talebi. Uludağ Üniversitesi Sosyal Bilimler Enstitüsü, Bursa.

Uncomtrade (2024). United Nations Comtrade Database, Erişim Linki: https://comtradeplus.un.org/ Erişim Tarihi: 28.09.2024

Usta, R. (2007). Türkiye'nin Fındık İhracatında Pazar ve Mamul Geliştirme Çalışmalarının 1996-2005 dönemi itibariyle incelenmesi. *Afyon Kocatepe Üniversitesi İİBF Dergisi,* 9(1), 155-172.

Yavuz, F., Birinci, A., Peker, K., & Atsan, T. (2004). Türkiye fındık sektörü ekonometrik modelinin oluşturulması ve politik analizlerde kullanımı. *Erzurum: Tarımsal Ekonomi Araştırma Enstitüsü.*

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Hybrid zoysia grass potential for turf use in transitional climate zones of Türkiye

Mert ÇAKIR[1]*, Songül SEVER MUTLU[2]

[1]Süleyman Demirel University, Faculty of Architecture, Department of Landscape Architecture, 32200, Isparta, Türkiye
[2]Akdeniz University, Faculty of Agriculture, Department of Horticulture, 07059, Antalya, Türkiye

***Corresponding author e-mail:** pmmertcakir@gmail.com

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Abstract: This study aimed to determine the winter survival of Turkish hybrid zoysia grasses under the transitional climate conditions of Isparta. The plant materials were the 214 hybrids developed from crosses involving *Zoysia japonica* and *Zoysia matrella* parents, and five commercial cultivars (Emerald, Empire, JaMur, Zenith, and Zeon) as controls. Spring green-up rates were assessed from May to July to evaluate post-winter recovery and adaptation. The findings suggest that a total of 37 hybrids (17%) did not survive winter cold stress. Significant variation in spring green-up rates was observed among the hybrids, with some outperforming both parents, demonstrating transgressive segregation. A total of 63 hybrids (29%) achieved 100% spring green-up, indicating their suitability for use in urban green spaces in regions with a transitional climate. Given the increasing importance of water conservation, these selected hybrids are highly recommended for use in larger-scale green area projects. Additionally, some hybrids outperformed commercial cultivars, suggesting that utilizing these locally developed hybrid lines could reduce dependence on foreign turfgrass varieties while offering sustainable solutions for landscape use without compromising turf quality.

Keywords: Hybrid lines, transitional climates, spring green-up, winter dormancy, zoysia grass.

Türkiye'nin geçiş iklim bölgelerinde hibrit zoysia çiminin kullanım potansiyeli

Öz: Bu çalışma, Isparta'nın geçiş iklim koşullarında Türk hibrit zoysia çimlerinin kışın hayatta kalma oranlarını belirlemeyi amaçlamıştır. Bitki materyali olarak *Zoysia japonica* ve *Zoysia matrella* ebeveynlerinin çaprazlamalarından elde edilen 214 melez ve kontrol olarak beş ticari çeşit (Emerald, Empire, JaMur, Zenith ve Zeon) kullanılmıştır. Kış sonrası geri gelme ve adaptasyonu değerlendirmek amacıyla, Mayıs'tan Temmuz'a kadar yeniden yeşillenme oranları belirlenmiştir. Bulgular, tüm hibritlerin %17'sini oluşturan toplam 37 hibrit hattın kış soğuk stresine dayanamadığını göstermiştir. Hibritler arasında ilkbaharda yeniden yeşillenme oranlarında önemli farklılıklar gözlemlenmiş olup bazı hatlar her iki ebeveynden de daha iyi performans göstererek transgresif açılım sergilemiştir. Toplamda 63 hibrit hat (%29) %100 yeşillenme oranına ulaşmış ve geçiş iklimine sahip bölgelerdeki kentsel yeşil alanlarda kullanım için uygun olduklarını göstermiştir. Su tasarrufunun giderek daha fazla önem kazandığı göz önünde bulundurulduğunda, bu hibritlerin geniş çaplı yeşil alan projelerinde kullanımı önerilmektedir. Ayrıca, bazı hibritler ticari çeşitlerden üstün performans sergilemiş olup bu yerel hibrit hatların kullanılması, çim sektöründeki dışa bağımlılığı azaltabilir ve yüksek çim kalitesini korurken peyzaj kullanımına sürdürülebilir çözümler sunabilir.

Anahtar kelimeler: Hibrit hatlar, geçiş iklimleri, ilkbaharda yeniden yeşillenme, kış dormansisi, zoysia çimi.

1. Introduction

Landscape design and management are essential for the efficient use of water resources, crucial for sustaining landscapes, enhancing aesthetic value, and maintaining ecological balance. However, the global water crisis has intensified due to rising demand from population growth, industrial activities, and agricultural irrigation, leading to widespread water scarcity that affects millions of people and ecosystems. Approximately 71% of the Earth's surface consists of water; however, just 2.5% is freshwater, the majority of which is sequestered in glaciers and aquifers (Kim & Lee, 2002), with less than 1% available for human use (Mishra, 2023). The depletion of water resources and

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rising demand underscore the need for sustainable water use strategies, especially in water-intensive sectors like agriculture and landscape management. Irrigated areas make up 20% of the world's arable land, consuming over 70% of global freshwater (Droogers et al., 2010). Thus, implementing water-saving techniques in landscape design is essential. Xeriscaping employs low water-requiring plants (Özyavuz & Özyavuz, 2012), and drip irrigation to minimize evaporation and runoff (Shareef et al., 2019), both of which are effective for water conservation. Additionally, rainwater harvesting systems capture and store rainwater for irrigation (Kinkade-Levario, 2007), while mulching helps preserve soil moisture and reduce evaporation (Patil Shirish, 2013). These techniques enhance water efficiency in landscapes, promoting ecological sustainability and economic savings. Selecting appropriate plants not only improves environmental sustainability but also enhances aesthetic appeal, conserves water, and protects biodiversity. Sustainable resource management requires the use of low-water plants in landscape designs due to the growing water scarcity.

Durability reflects a plant's ability to withstand harsh environments. It is necessary to choose winter-hardy species for colder climates and drought-resistant varieties for hot, dry regions. For example, turfgrass species like *Cynodon dactylon* L. (bermudagrass) and *Zoysia japonica* Steud. (zoysia grass) are resilient to drought and heavy foot traffic, making them ideal for parks and sports areas in tropical and subtropical regions. In transitional climates, where both cool-season (C_3) and warm-season (C_4) turfgrasses can thrive, choices should consider intended use, aesthetic goals, maintenance capabilities, and sustainability objectives. C_4 turfgrasses are generally more suitable due to their lower water requirements, which is increasingly important in times of water scarcity. They also demand less frequent irrigation, mowing, fertilization, and pesticide application, resulting in lower energy and material use, and a smaller carbon footprint. However, Çakır & Tuğluer (2021) revealed that predominantly C_3 turfgrass mixtures were used in three urban parks in Isparta, indicating an underutilization of more sustainable turfgrass options.

Improving water use efficiency in landscape management and agricultural irrigation is essential under increasing water scarcity. One effective strategy is using drought-resistant species and varieties, with C_4 plants being significant alternatives due to their water-saving potential. In transitional climate zones, prioritizing C_4 species over C_3 can enhance sustainable landscape practices by optimizing water use, making C_4 turfgrasses a better option for sustainable landscaping.

Zoysia grass is a perennial C_4 turfgrass, valued for its dense texture and resilience against drought, foot traffic, weeds, diseases, and pests, and has recently been adopted in Türkiye. However, its widespread use is limited because of slow growth rate, prolonged establishment and dormancy periods, insufficient adaptability studies for Türkiye's climates, and high costs of seeded and hybrid varieties. Despite these challenges, zoysia grass excels in shaded environments compared to bermudagrass, which tends to thin out. It also requires less maintenance, offers superior drought tolerance, and provides dense coverage that suppresses weeds.

The *Zoysia* genus includes eleven species, but only a few are commonly used as turfgrass, including *Z. japonica* (Steud.), *Z. matrella,* (L.) Merr., *Z. pacifica* (Goudsw.) M. Hotta & Kuroki, and hybrids like *Z. japonica* × Z. *matrella* and *Z. japonica* × *Z. pacifica* (Magni et al., 2017). These species differ in both morphological characteristics and resilience to stress conditions (Riffell et al., 1995; Dunn et al., 1999; Reinert & Engelke, 2001; White et al., 2001; Patton & Reicher, 2007; Trappe et al., 2011; Wherley et al., 2011; Patton et al., 2017; Irkörücü, 2018). Each *Zoysia* species offers distinct advantages, suggesting potential for increased use in Türkiye as research and applications expand.

Hybridization in plants enhances genetic diversity and improves specific traits, often resulting in new species or varieties. Plant breeders commonly use this method to develop high-performance varieties, with hybrid zoysia grasses exemplifying this approach. These hybrids, created by crossbreeding species like *Z. japonica, Z. pacifica,* and *Z. matrella*, are particularly well-suited for warm climates, making them ideal for landscaping and sports fields due to their resilience. Hybrids involving *Z. japonica* are especially promising for transitional climates, offering cold resistance, improved water use efficiency, disease resistance, and lower maintenance requirements (Reinert & Engelke, 2001; White et al., 2001). The combination of *Z. japonica* and *Z. matrella* is advantageous, as *Z. japonica* provides cold tolerance and rapid growth, while *Z. matrella* offers finer texture, superior turf quality, and better shade resistance (Patton et al., 2017). By selecting these species as primary and secondary parents, breeders can create optimal traits for various environments. It was hypothesized that hybrid zoysia grasses with strong survival rates can establish high-quality, sustainable green spaces in Türkiye's transitional climate, serving as a viable alternative to traditional C_3 grass species. This study aimed to determine the winter survival potential of the Turkish hybrid zoysia grass lines under the transitional climate conditions of Isparta. The results of this study are expected to contribute to the creation of high-quality and sustainable green areas in transitional climates.

2. Materials and Methods

The field evaluation was conducted in Isparta province (37.808333 °N, 30.527500 °E), Türkiye, during 2020 and 2021. A total of 214 hybrid lines developed through reciprocal interspecific hybridizations between *Z. japonica* and *Z. matrella* at Akdeniz University (Antalya, Türkiye), as part of the "TAGEM/17/ARGE/15" project were evaluated in the study. These hybrid lines, with potential for use as turfgrass, were selected through a preliminary evaluation of hybrid genotypes developed based on general turfgrass characteristics such as growth rate, leaf texture (coarse or fine), color (dark or light green), and growth habit (dwarf or upright). Alongside the hybrids, two zoysia grass lines (*Z. japonica* and *Z. matrella*) used as parents in the crosses, and five commercially available zoysia grass cultivars (Emerald, Empire, JaMur, Zenith, and Zeon) as controls were included in the study. Commercially available zoysia grass cultivars preferred in green spaces in the Mediterranean region of Türkiye were selected for the study. Their adaptation to Mediterranean growing conditions of Türkiye has been reported (Avcıoğlu & Geren; 2012; Severmutlu et al., 2011a; 2011b; Kır et al., 2018). The adaptation of the commercial varieties used as controls has not been determined in Isparta. Among the 214 hybrid lines, 80 were produced from the crossbreeding of *Z. japonica* (♀) with *Z. matrella* (♂), while 134 lines resulted from the crossbreeding of *Z. matrella* (♀) with *Z. japonica* (♂).

The research area is located in the transitional climate zone, which includes both Mediterranean and continental climates. Based on 33 years of temperature observations for Isparta, the annual average temperature for the province is 12.5 °C. Furthermore, the annual average maximum temperature is 19.0 °C, whereas the annual average minimum temperature is 6.4 °C. The warmest months in Isparta are July and August, and the coldest months are January and February. The annual precipitation is 568 mm, accompanied by average of 99 rainy days per year (General Directorate of Meteorology, 2024). Table 1 presents the climate data for Isparta during the trial period, showing seasonal temperature and precipitation variations.

Table 1. Monthly climate data for Isparta: temperature and precipitation averages.

Months	Avg. Temp. (°C)	Avg. High Temp. (°C)	Avg. Low Temp. (°C)	Avg. Monthly Precip. (mm)
September2020	19.8	28.1	11.8	14.7
October 2020	14.5	23.2	7.6	35.6
November 2020	9.2	15.6	2.5	41.6
December 2020	4.5	9.2	1.3	58.9
January 2021	2.2	7.2	-1.2	60.7
February 2021	3.8	8.7	0.5	50.1
March 2021	7.1	13.0	1.6	52.3
April 2021	11.8	18.4	5.2	48.9
May 2021	17.0	19.0	9.3	49.8
June 2021	21.2	23.5	13.4	28.9
July 2021	25.1	32.4	17.1	17.8
August 2021	24.6	33.1	16.8	15.4

Table 2. Soil properties of the trial area.

Analysis Name		Analysis Method	Unit	Results
Texture	Sand	Bouyoucos Hydrometer	%	32
	Silt	Bouyoucos Hydrometer	%	25
	Clay	Bouyoucos Hydrometer	%	43
EC		(1:2.5)	dS/m	0.22
pH		(1:2.5)	-	7.81
Lime		(Calcimetric)	%	14.41
Organic Matter		(Walkley Black)	%	1.10
Nitrogen		(Kjeldahl)	ppm	650
Phosphorus		(Olsen-Spectrophotometer)	ppm	11.50
Potassium		(A. Acetate-AAS)	ppm	210.77
Calcium		(A. Acetate-AAS)	ppm	8,798.20
Magnesium		(A. Acetate-AAS)	ppm	611.22
Iron		(DTPA-AAS)	ppm	2.74
Copper		(DTPA-AAS)	ppm	1.29
Manganese		(DTPA-AAS)	ppm	8.65
Zinc		(DTPA-AAS)	ppm	0.98

The field treatment plots, measuring 1 m × 1 m, were organized in a trial designed as a randomized complete block with three replications. The soil sample taken from a depth of 0-30 cm from the experimental field was analyzed in accordance with the principles reported by Jackson (1962). The pH, salinity, organic matter content, texture classes, and nutrient contents of the soil in the experimental field are presented in Table 2. The experimental field has a clay loam texture, non-saline (low EC), slightly alkaline pH, high lime, and low organic matter content.

Prior to planting, the trial area was cultivated between August and September and mechanically cleared of weeds. The topsoil was graded and rolled to ensure an even surface. Throughout the trial period, no fertilizers or pesticides were applied. On September 21, 2020, three grass plugs were harvested from each genotype cultivated in the Akdeniz University Research Field using a grass profile sampling tool with a diameter of 10.8 cm (A = 91.61 cm^2). The harvested grass profiles were promptly transported to Isparta, where they were individually planted in the designated plots on the same day. Following planting, irrigation was applied using a sprinkler system at a rate of 7 mm three times daily for two weeks to support establishment and subsequently reduce visual turfgrass stress symptoms. Weeds were mechanically controlled at regular intervals, and no incidents requiring pest control were recorded.

The assessment of spring green-up, indicative of both the transition from winter dormancy to active spring growth and winter survival, was conducted between May and July. Spring green-up was quantified using a visual estimate scale ranging from 0% to 100%, where 0% indicates the absence of green vegetation cover and 100% signifies complete coverage of the plot with green vegetation (Severmutlu et al., 2011b). The data were analyzed using the PROC GLM procedure in SAS (version 9.1; SAS Institute, Cary, NC, USA). Mean comparisons were performed using Fisher's protected least significant difference (LSD) test at a 0.05 significance level.

3. Results and Discussion

The optimal growth temperature for *Zoysia* species ranges from 25 to 35 °C (Xie, 2015). Like other C_4 turfgrass species, *Zoysia* species enter a dormant state during the fall and winter months as temperatures decrease. *Zoysia* species and cultivars vary in their genetic ability concerning the onset of dormancy, tolerance to low temperatures in winter months, and coming back from dormancy in the spring (Pompeiano et al. 2014; Engelke & Anderson 2003). During the dormant period, turfgrasses lose their green color and turn straw yellow, and they typically return to their green color as temperatures rise in the spring. Consequently, it is advantageous for warm-season turfgrasses to enter dormancy late in the fall and to green up early in the spring, maintaining their green color for an extended period. As air temperatures dropped in late November, hybrid zoysia grasses began to enter dormancy. From mid to late May, as temperatures began to rise, the plants began their green-up phase. Table 3 presents data on the spring green-up of the hybrids observed between May and July. Spring green-up refers to the transition of dormant turfgrass from a winter-damaged state to active growth (Morris & Shearman, 2006). The data on the spring green-up of the genotypes are critical for assessing their post-winter adaptation success. Understanding these characteristics can help to identify and develop more resilient cultivars that can withstand winter stresses and recover effectively in the spring. While most hybrids exhibited a relatively low spring green-up rate on May 19, a significant increase was observed from June 10 onwards. This trend suggests that the spring green-up process accelerated in response to the increased temperatures observed in the second half of May. Similarly, Rimi et al. (2011), Severmutlu et al. (2011b), Pompeiano et al. (2014) and Oh et al. (2015) reported that rising temperatures accelerate spring green-up. This phenomenon is attributed to enhanced photosynthetic activity and metabolic processes stimulated by temperature fluctuations. Significant differences were found among hybrids in the spring green-up rate (Table 3). For example, the MJ46 genotype showed a 60% spring green-up on the 19th of May, while many of the other genotypes did not begin the spring green-up process on that date.

These results highlight the existence of considerable variation in the genetic ability of hybrids to adapt to the prevailing climatic and soil conditions in the region. Previous studies have also reported both intra- and interspecific variation in spring green-up temperatures among C_4 turfgrasses (Croce et al., 2001; Severmutlu et al., 2011b). The 63 different hybrids (29%) namely, JM-14, JM-19, JM-25, JM-30, JM-38, JM-4, JM-7, JM-9, JM-e46, JM-e47, JM-e51, JM-e55, JM-G75, JM-h77, JM-h79, JM-z57, JM-z61, JM-z62, JM-z69, JM-z74, JM-zm1, JM-zm3, MJ-103, MJ-104, MJ-11, MJ-111, MJ-112, MJ-12, MJ-17, MJ-18, MJ-22, MJ-24, MJ-25, MJ-26, MJ-42, MJ-44, MJ-46, MJ-49, MJ-5, MJ-50, MJ-53, MJ-54, MJ-56, MJ-59, MJ-6, MJ-62, MJ-65, MJ-69, MJ-74, MJ-8, MJ-87, MJ-88, MJ-92, MJ-95, MJ-e115, MJ-e116, MJ-mz1, MJ-mz10, MJ-mz2, MJ-mz4, MJ-mz9, MJ-T2, and MJ-T5 exhibited a rapid spring green-up process beginning on May 19, achieving a 100% spring green-up rate within a short period. These hybrid lines represent promising candidates for successful adaptation in transitional climate, such as Isparta.

Table 3. Spring green-up rates (%) of the genotypes.

No.	Genotypes	May 19	June 10	June 22	July 1	No.	Genotypes	May 19	June 10	June 22	July 1
	Commercial Cultivars					65	JM-z62	10	0	70	100
1	Emerald	1	5	10	25	66	JM-z63	5	15	40	75
2	Empire	5	15	85	100	67	JM-z64	0	0	0	0
3	JaMur	25	75	100	100	68	JM-z65	5	10	40	80
4	Zenith	20	30	60	90	69	JM-z66	5	10	35	70
5	Zeon	5	25	50	85	70	JM-z67	5	15	25	50
	Parental Lines					71	JM-z68	5	35	60	90
1	*Z. matrella*	1	8	15	30	72	JM-z69	10	40	85	100
2	*Z. japonica*	0	10	35	72	73	JM-z70	5	25	55	85
	Hybrids (*Z. japonica*♀ x *Z. matrella*♂)					74	JM-z71	0	0	5	10
1	JM-10	5	10	45	70	75	JM-z72	5	5	10	20
2	JM-11	5	10	35	60	76	JM-z73	1	0	0	0
3	JM-12	5	10	20	40	77	JM-z74	10	30	70	100
4	JM-13	5	25	60	90	78	JM-zm1	35	90	100	100
5	JM-14	10	35	70	100	79	JM-zm2	10	30	70	95
6	JM-15	1	5	20	40	80	JM-zm3	5	35	70	100
7	JM-16	5	20	50	70		Hybrids (*Z. matrella*♀ x *Z. japonica*♂)				
8	JM-17	0	0	0	0	1	MJ-1	0	0	0	0
9	JM-19	35	90	95	100	2	MJ-10	5	35	75	95
10	JM-2	5	35	55	85	3	MJ-100	0	0	0	0
11	JM-20	0	10	0	0	4	MJ-101	5	35	55	90
12	JM-21	5	5	30	50	5	MJ-102	1	10	35	55
13	JM-22	0	0	0	0	6	MJ-103	15	50	90	100
14	JM-23	5	25	45	75	7	MJ-104	5	25	70	100
15	JM-24	10	15	40	70	8	MJ-105	0	0	0	0
16	JM-25	10	40	70	100	9	MJ-106	0	0	0	0
17	JM-26	5	1	30	75	10	MJ-107	1	20	45	75
18	JM-27	0	0	0	0	11	MJ-108	0	0	0	0
19	JM-28	0	0	0	0	12	MJ-109	5	20	70	85
20	JM-29	5	25	50	85	13	MJ-11	10	45	95	100
21	JM-3	5	35	60	90	14	MJ-110	1	0	5	20
22	JM-30	10	30	65	100	15	MJ-111	5	40	85	100
23	JM-31	10	35	60	95	16	MJ-112	10	35	70	100
24	JM-32	0	25	45	70	17	MJ-113	10	20	50	75
25	JM-33	1	10	40	75	18	MJ-114	5	15	40	75
26	JM-34	5	10	30	65	19	MJ-12	15	90	100	100
27	JM-35	0	0	0	0	20	MJ-13	10	35	50	80
28	JM-36	0	0	0	0	21	MJ-14	0	1	5	10
29	JM-37	0	0	10	25	22	MJ-15	5	15	50	85
30	JM-38	35	45	100	100	23	MJ-16	5	25	65	95
31	JM-39	0	0	0	0	24	MJ-17	15	25	90	100
32	JM-4	10	35	75	100	25	MJ-18	10	25	75	100
33	JM-40	15	25	60	85	26	MJ-19	0	0	0	0
34	JM-41	1	5	10	25	27	MJ-2	0	5	10	25
35	JM-42	0	0	0	0	28	MJ-20	5	15	40	65
36	JM-43	0	0	0	0	29	MJ-21	0	5	10	15
37	JM-44	1	10	40	65	30	MJ-22	20	30	80	100
38	JM-5	10	30	70	95	31	MJ-23	5	30	50	80
39	JM-6	0	0	0	0	32	MJ-24	10	40	32	100
40	JM-7	20	50	80	100	33	MJ-25	20	50	90	100
41	JM-8	5	30	50	85	34	MJ-26	5	45	80	100
42	JM-9	10	45	75	100	35	MJ-27	5	25	50	85
43	JM-e44	0	0	0	0	36	MJ-28	5	20	50	85
44	JM-e46	10	40	95	100	37	MJ-29	5	25	55	70
45	JM-e47	10	35	75	100	38	MJ-3	0	0	0	0
46	JM-e48	5	10	55	80	39	MJ-30	5	15	39	85
47	JM-e49	10	35	55	85	40	MJ-31	0	0	0	0
48	JM-e50	10	10	35	70	41	MJ-32	5	15	35	70
49	JM-e51	25	90	100	100	42	MJ-33	0	0	0	0
50	JM-e52	1	1	5	20	43	MJ-34	1	10	20	35
51	JM-e53	0	0	0	0	44	MJ-35	5	35	60	95
52	JM-e54	5	5	15	25	45	MJ-36	5	30	50	80
53	JM-e55	10	40	95	100	46	MJ-37	10	30	75	95
54	JM-g75	15	50	90	100	47	MJ-38	15	45	60	85
55	JM-h76	5	15	50	85	48	MJ-39	0	10	30	60
56	JM-h77	40	50	85	100	49	MJ-4	0	5	15	30
57	JM-h78	0	1	10	25	50	MJ-40	5	15	50	80
58	JM-h79	30	95	100	100	51	MJ-42	20	90	100	100
59	JM-z	5	10	10	25	52	MJ-43	1	5	10	25
60	JM-z56	10	45	45	75	53	MJ-44	5	30	70	100
61	JM-z57	10	45	80	100	54	MJ-45	0	10	30	70
62	JM-z59	1	1	10	25	55	MJ-46	60	90	100	100
63	JM-z60	5	5	10	20	56	MJ-47	5	20	55	85
64	JM-z61	15	40	70	100	57	MJ-48	0	5	5	20

Table 3. Spring green-up rates (%) of the genotypes (continued).

No.	Genotypes	May 19	June 10	June 22	July 1	No.	Genotypes	May 19	June 10	June 22	July 1
58	MJ-49	5	30	80	100	97	MJ-84	0	0	0	0
59	MJ-5	5	30	70	100	98	MJ-85	5	15	40	80
60	MJ-50	5	15	70	100	99	MJ-86	5	30	55	85
61	MJ-51	5	20	45	75	100	MJ-87	15	40	85	100
62	MJ-52	1	15	20	40	101	MJ-88	10	70	85	100
63	MJ-53	10	45	70	100	102	MJ-89	5	25	60	85
64	MJ-54	10	45	85	100	103	MJ-9	5	25	60	90
65	MJ-55	5	1	10	25	104	MJ-90	5	5	45	85
66	MJ-56	10	75	80	100	105	MJ-91	1	0	5	10
67	MJ-57	5	30	65	95	106	MJ-92	15	45	100	100
68	MJ-58	0	0	0	0	107	MJ-93	5	20	60	85
69	MJ-59	20	35	75	100	108	MJ-94	5	25	55	85
70	MJ-6	5	30	70	100	109	MJ-95	15	40	90	100
71	MJ-60	5	10	15	30	110	MJ-96	5	10	40	80
72	MJ-61	0	0	0	0	111	MJ-97	5	10	40	65
73	MJ-62	10	40	100	100	112	MJ-98	1	5	10	25
74	MJ-63	0	0	0	0	113	MJ-99	0	0	0	0
75	MJ-64	0	0	0	0	114	MJ-e115	10	40	70	100
76	MJ-65	15	60	90	100	115	MJ-e116	10	40	85	100
77	MJ-66	0	5	15	30	116	MJ-mz1	10	40	75	100
78	MJ-67	1	5	5	15	117	MJ-mz10	10	40	95	100
79	MJ-68	0	0	0	0	118	MJ-mz11	5	40	40	75
80	MJ-69	5	20	50	100	119	MJ-mz12	1	10	10	25
81	MJ-7	0	0	0	0	120	MJ-mz2	35	80	95	100
82	MJ-70	5	15	35	70	121	MJ-mz3	0	0	10	20
83	MJ-71	1	0	10	30	122	MJ-mz4	10	30	70	100
84	MJ-72	0	0	0	0	123	MJ-mz5	1	5	35	70
85	MJ-73	1	15	65	90	124	MJ-mz6	0	0	0	0
86	MJ-74	5	25	70	100	125	MJ-mz7	0	0	0	0
87	MJ-75	1	15	35	75	126	MJ-mz8	5	10	50	80
88	MJ-76	0	0	0	0	127	MJ-mz9	10	35	70	100
89	MJ-77	5	5	30	65	128	MJ-T1	5	20	60	95
90	MJ-78	10	25	45	70	129	MJ-T2	15	40	80	100
91	MJ7-9	1	5	40	75	130	MJ-T3	1	5	10	20
92	MJ-8	30	75	100	100	131	MJ-T4	1	15	40	70
93	MJ-80	10	20	20	40	132	MJ-T5	10	45	85	100
94	MJ-81	1	1	10	20	133	MJ-T6	5	20	35	55
95	MJ-82	0	0	0	0	134	MJ-T7	5	5	10	15
96	MJ-83	5	5	20	50		$LSD_{0.05}$	4.9	9.6	13.2	16.8

On the other hand, 37 hybrids (17%) including JM-17, JM-20, JM-22, JM-27, JM-28, JM-35, JM-36, JM-39, JM-42, JM-43, JM-6, JMe-44, JMe-53, JMz-64, JMz-73, MJ-1, MJ-100, MJ-105, MJ-106, MJ-108, MJ-19, MJ-3, MJ-31, MJ-33, MJ-58, MJ-61, MJ-63, MJ-64, MJ-68, MJ-7, MJ-72, MJ-76, MJ-82, MJ-84, MJ-99, MJ-mz6, and MJ-mz7 had a 0% spring green-up rate, indicating they suffered from winterkill and fully died out. These hybrids probably did not initiate dormancy until it got too cold for them to survive under cold winter conditions in Isparta. These underperforming hybrid lines may have slower growth rates or be less tolerant of environmental stresses. These hybrids may require very short dormancy and it may be conceivable to test these hybrids in regions having mild winter climatic conditions to evaluate their adaptability and survival.

To effectively illustrate the overall spring green-up performance trends, the analysis conducted using quartiles (25%) is presented in Table 4. A significant proportion of the hybrids (49%) exhibited relatively high performance, achieving a spring green-up rate of 76% or above by July 1. These elevated adaptation rates suggest that certain hybrid zoysia grasses may represent a promising option for transition climatic zones. This performance is particularly important considering that hybrid zoysia grasses have been highlighted in literature for their superior tolerance to environmental stressors, including drought and cold. Beard (1973) reported that zoysia grass had a greater tolerance to freezing than other warm-season turf grasses, and Dunn et al. (1999) demonstrated a wide range of cold tolerance among zoysia grass cultivars. The high spring green-up rates of some genotypes, which reached 100% green-up, echo the results of the study by Pompeiano et al. (2014), who reported strong adaptability and rapid green-up in certain *Zoysia* genotypes in the transitional climate zone of Italy. Figure 1 visualizes the frequencies and distribution of spring green-up rates across the genotypes on the specified observation dates.

0% spring green-up: This group includes 37 distinct hybrids, which faced difficulty adapting to Isparta's climate. This suggests that these hybrids probably suffered from winter kill Surprisingly, in 15 of these hybrids (41%), the maternal parent was *Z. japonica* which is well known for its best tolerance to low temperatures among all zoysia grass species (Emmons, 2000). This result suggests that resistance to cold temperatures may not be associated with maternal inheritance. It also further indicating large intra and inter-specific variation exist among zoysia grasses. Overall the hybrids in this group apparently have low dormancy requirements and, hence do not become dormant before the onset of cold winter onset. Hence, they could not survive winter cold in a non-dormant state, making these genotypes unsuitable for Isparta.

1-25% spring green-up: The range encompasses 25 distinct hybrids. The genotypes that demonstrated markedly suboptimal spring green-up performance were also unable to thrive in the environmental conditions of Isparta. The inability of these genotypes to demonstrate complete spring green-up can be attributed to their higher temperature requirements and their relatively slow growth/regeneration habit.

26-50% spring green-up: A total of 12 hybrids are present within this group. The genotypes exhibited low-to-medium spring green-up rates. These genotypes exhibited some degree of success, although the results were far from optimal. Since their regional adaptations have only been partially achieved, further improvement studies are necessary to enhance success in other settings. These genotypes may exhibit greater efficacy under certain ecological niches where springs are earlier or warmer than Isparta region.

51-75% spring green-up: A total of 34 genotypes within this group have shown relative success in adapting to the climatic conditions of Isparta. These genotypes were characterized by their relatively high spring green-up rates and moderate resistance to stress factors. Further testing is necessary to ascertain the optimal conditions for these genotypes. There is potential for these genotypes to be cultivated on a larger scale, provided they continue to adapt well to the prevailing environmental conditions. The likelihood of these genotypes serving as a sustainable option in the transitional climate zone is considerable.

76-99% spring green-up: The presence of 43 distinct genotypes within this group indicates significant performance under Isparta conditions. These genotypes are promising regarding both spring green-up, winter survival, and overall adaptation to the region. Utilizing these genotypes in green spaces in Isparta will potentially contribute to water conservation efforts. Additionally, testing these genotypes in different transition zones could help determine their success in other regions. Future studies should focus on a more detailed examination of these genotypes, particularly evaluating characteristics such as drought tolerance and water use efficiency.

100% spring green-up: This group includes 63 distinct genotypes, demonstrating a notable degree of success. These genotypes are well-suited to both the climatic and environmental conditions of Isparta, indicating that they can effectively complete their growth cycles. It is recommended that these genotypes be widely disseminated and serve as references for future similar projects. They may represent optimal choices for water conservation, durability, and longevity. Future studies should conduct a more detailed examination of these genotypes, focusing on their drought tolerance and water use efficiency. The genotypes in this group show potential for commercial application since their performance is likely to be comparable to, if not superior to, that of currently available commercial genotypes. However, their success should be validated through testing in larger areas. Moreover, assessments of their stress resistance and other turf performance characteristics are crucial before implementing them widely.

To provide a comprehensive assessment, Table 5 presents the means, standard deviations, and ranges for the spring green-up data of the hybrids, parental lines, and commercial cultivars used in the study. The findings show that, up until the second half of June, some of the hybrids outperformed commercial checks in terms of spring green-up performance and then showed comparable results. For example, on June 10, the spring green-up ratio of some hybrids was as high as 95%, whereas it was only between 5 and 75% in the commercial cultivars. Commercial zoysia grass varieties used in this study are widely used in the turfgrass market in Türkiye. These lines serve as benchmarks, showcasing stable performance under specific environmental conditions. To evaluate the commercialization potential of hybrid lines, it is crucial to conduct direct comparisons with existing commercial varieties. Such comparisons highlight the relative advantages or disadvantages of the hybrid lines, providing insight into their competitive position against current market alternatives.

Several individual hybrid lines, including MJ-46 and JM-19, have surpassed the performance of all the commercial checks, which in turn indicates their potential for commercialization. The commercial cultivars also demonstrated significant differences in their spring green-up rate among them. JaMur and Empire consistently excelled throughout the measurement periods, reaching 100% green-up in June 22 and July 1, respectively. Emerald ranked the lowest, achieving a maximum spring green-up rate of only 25% in Isparta. Zeon followed with a maximum rate of 85%, showing gradual improvement over time. Zenith attained a maximum spring green-up rate of 90%. Empire also performed well, reaching a maximum of 100%. The performance of commercial varieties, especially JaMur and Empire also supports the hypothesis that zoysia grass can be an alternative to C_3 turfgrass species in Isparta.

In hybridization studies, the performance and genetic characteristics of parental genotypes determine the quality and adaptability of the resulting hybrids. The parents play a crucial role in determining the hybrids' resistance to various stress factors, including diseases, drought, and adverse climatic conditions. Comparative analyses are essential for assessing the degree of genetic divergence between the hybrids and their parent varieties. By evaluating the hybrids in relation to the parental lines, researchers can ascertain whether the desired traits have been effectively expressed in the hybrid lines. The parental lines exhibited lower spring green-up rates compared to the hybrids. On June 10, when the mean spring green-up rates of *Z. japonica* and *Z. matrella* parents were 10% and 8%, respectively, the average spring green-up rate of hybrids (n = 214) varied from 0 to 95% (Table 5). Thus, transgressive segregation was evident for earlier spring green-up and better winter survival among hybrid progenies. In general, the parental line *Z. japonica* demonstrated better spring green-up performance than *Z. matrella*.

Table 4. Distribution of genotypes according to spring green-up rates as of July 1.

Spring green-up percentage range	Number of the genotypes	% of all genotypes
0%	(15)◊+(22)▫=37	17
1% - 25%	(10)+(15)=25	12
26% - 50%	(8)+(4)=12	6
51% - 75%	(14)+(20)=34	16
76 % - 99%	(15)+(28)=43	20
100%	(22)+(41)=63	29

◊, ▫: Numbers in the first parentheses represent *Z. japonica* ♀ x *Z. matrella* ♂ hybrids, and numbers in the second parentheses represent *Z. matrella* ♀ x *Z. japonica* ♂ hybrids.

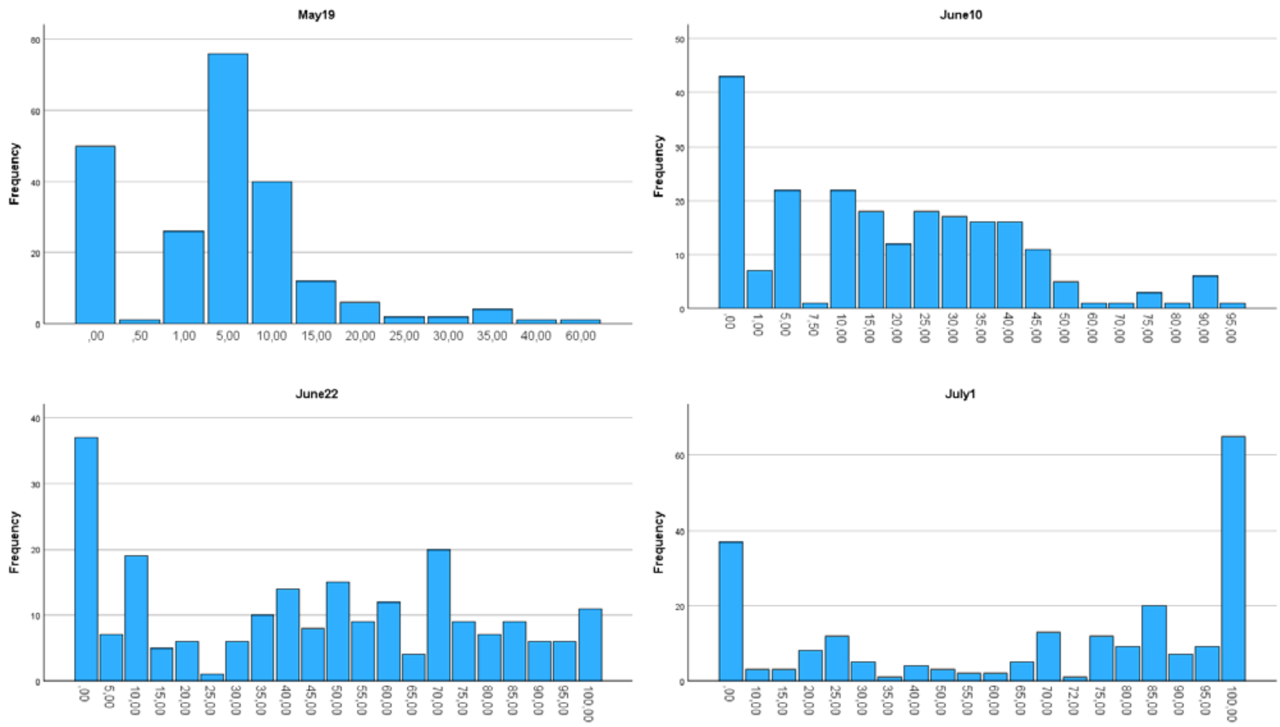

Figure 1. Spring green-up frequency distribution of genotypes.

Table 5. Means, standard deviations, and ranges for spring green-up of hybrid zoysia grass genotypes developed from crosses of *Z. japonica* with *Z. matrella* along with parental lines and five commercial zoysia grass cultivars (Emerald, Empire, JaMur, Zenith, and Zeon) in Isparta, Türkiye.

	Commercial Cultivars		Parental Lines		Hybrid lines			
			Z. japonica	*Z. matrella*	*Z. japonica*♀ x *Z. matrella*♂		*Z. matrella*♀ x *Z. japonica*♂	
	X̄ ± SE	m-M	X̄ ± SE	X̄ ± σ	X̄ ± SE	m-M	X̄ ± SE	m-M
May 19	11.2±2.49	1-25	0.0±0.00	0.5±0.00	7.40±0.57	0-40	6.03±0.39	0-60
June 10	30.0±6.53	5-75	10.0±1.15	7.5±1.44	21.80±1.48	0-95	21.78±1.04	0-90
June 22	61.0±7.51	10-100	35.0±1.73	15.0±1.73	42.63±2.09	0-100	44.51±1.62	0-100
July 1	80.0±6.45	25-100	71.7±1.15	30.0±1.73	61.19±2.50	0-100	63.25±1.91	0-100

X̄: Mean; SE: Standart Error; m: Minimum; M: Maximum

4. Conclusion

This study represents one of the first comprehensive investigations into the performance of *Zoysia* species in the transitional climate zones of Türkiye. It found that some hybrid zoysia grasses are more resilient to winter cold and green up faster in spring, with 50% showing green-up rates between 76% and 100%, outperforming commercial cultivars. These Turkish-origin local hybrids have strong potential for reducing water usage in green areas and may reduce dependency on imported turfgrass.

Since the study was conducted only in Isparta, the findings may not be generalizable to other regions. Further studies are needed in both transitional and different climatic zones. Evaluating the performance of these hybrids in different climatic and soil conditions may help to better understand the general adaptation potential of the zoysia grasses. Moreover, additional research should be done on the long-term performance of these hybrids, especially their resilience to deficient irrigation conditions and climate change.

Conflict of interest

The authors declare no conflicts of interest.

Authorship contribution statement

M.Ç: Conceptualization, methodology, investigation, resources, data curation, formal analysis, visualization, writing – original draft, writing – review & editing, project administration. S.S.M: Conceptualization, methodology, resources, visualization, writing – original draft, writing – review & editing.

References

Avcıoğlu, R., & Geren, H. (2012). Investigations on the performances of some warm season turf grasses under Mediterranean climate. *Anadolu, Journal of AARI*, 22(1), 1-17.

Beard, J. B. (1973). Science and culture. In: Hall, P. and Cliffs, E. (eds) Turfgrass. American Society of Agronomy, Inc., Crop Science Society of America, Inc. and Soil Science Society of America, Inc.: NJ, USA.

Croce, P., De Luca, A., Mocioni, M., Volterrani, M., & Beard, J. B. (2001). Warm-season turfgrass species and cultivar characterizations for a Mediterranean climate. *International Turfgrass Society Research Journal*, 9:855–859.

Çakır, M., & Tuğluer, M. (2021). Determination of turfgrass species used in green areas in ısparta city center and evaluation of their quality. 1st International Architectural Sciences and Application Symposium. October 27-29, Isparta, Türkiye.

Droogers, P., Immerzeel, W. W., & Lorite, I. J. (2010). Estimating actual irrigation application by remotely sensed evapotranspiration observations. *Agricultural Water Management,* 97(9), 1351-1359.

Dunn, J. H., Bughrara, S. S., Warmund, M. R., & Fresenburg, B. F. (1999). Low temperature tolerance of Zoysiagrasses. *HortScience*, 34(1), 96-99.

Emmons, R. (2000). Turfgrass Science and Management Third Edition, Delmar Publishers, USA.

Engelke, M. C., & Anderson, S. (2003). Zoysiagrass (*Zoysia* spp.). In: Casler MD, Duncan RR (eds) Turfgrass biology and breeding. Wiley, Hoboken, NJ, pp 271–285.

General Directorate of Meteorology. (2024). Seasonal Normals for Provinces (1991-2024). Access Date: 30.07.2024. https://www.mgm.gov.tr/veridegerlendirme/il-ve-ilceler-istatistik.aspx?k=A&m=ISPARTA.

Irkörücü, D. (2018). *Evaluation of hybrid Zoysiagrass (Z. japonica x Z. pasifica) for their turfgrass performance and suitability for green spaces*. [MSc Thesis, Akdeniz University], Antalya, Türkiye.

Jackson, M. L. (1962). Soil Chemical Analysis. Prentice Hall Inc. Englewoods Cliffs, N.I., USA.

Kır, B., Salman, A., Avcıoğlu, R., & Özkan, Ş. S. (2018). Investigations on the quality characteristics of some new turf alternatives under Mediterranean climatic conditions. *Journal of Agriculture Faculty of Ege University,* 55(4), 389-395. https://doi.org/10.20289/zfdergi.393813

Kim, Y., & Lee, W. G. (2022). Seawater and Its Resources. In *Seawater Batteries: Principles, Materials and Technology* (pp. 1-35). Singapore: Springer Nature Singapore.

Kinkade-Levario, H. (2007). Design for Water: Rainwater Harvesting, Stormwater Catchment, and Alternate Water Reuse. Gabriola Island, BC: New Society Publishers.

Magni, S., Pompeiano, A., Gaetani, M., Caturegli, L., Grossi, N., Minelli, A., & Volterrani, M. (2017). Zoysiagrass (*Zoysia* spp. Willd.) for European Lawns: a Review. *Italian Journal of Agronomy*, 12(4), 395-402.

Mishra, R. K. (2023). Fresh water availability and its global challenge. *British Journal of Multidisciplinary and Advanced Studies*, 4(3), 1-78.

Morris, K. N., & Shearman, R. C. (2006). NTEP turfgrass evaluation guidelines. National Turfgrass Evaluation Program. https://www.ntep.org/pdf/ratings.pdf

Oh, J. S., Lee, Y. J., & Lee, S. K. (2015). Late Fall Nitrogen Application and Turf Cover for Zoysiagrass (*Zoysia japonica*) Spring Green-up. *Weed & Turfgrass Science*, 4(4), 383-389.

Özyavuz, A., & Özyavuz. M. (2012). Xeriscape in landscape design. In Özyavuz, M. (ed) Landscape planning, IntechOpen, London, United Kingdom: pp. 353–60. https://doi.org/10.5772/38989.

Patil Shirish, S., Kelkar Tushar, S., & Bhalerao Satish, A. (2013). Mulching: A soil and water conservation practice. *Research Journal of Agricultural Sciences*, 2320, 6063.

Patton, A. J., & Reicher, Z. J. (2007). Zoysiagrass species and genotypes differ in their winter injury and freeze tolerance. *Crop Science*, 47, 1619-1627.

Patton, A. J., Schwartz, B. M., & Kenworthy, K. E. (2017). Zoysiagrass (*Zoysia* spp.) history, utilization, and improvement in the United States: A review. *Crop Science*, 57, 1-12.

Pompeiano, A., Grossi, N., Guglielminetti, L., & Volterrani, M. (2014). Winter color retention and spring green-up of zoysiagrass genotypes in southern Europe. *European Journal of Horticultural Science*, 79, 158-66.

Reinert, J. A., & Engelke, M. C. (2001). Resistance in zoysiagrass (*Zoysia* spp.) to the tropical sod webworm (*Herpetogramma phaeopteralis*). *International Turfgrass Society Research Journal*, 9, 798-801.

Riffell, S. K., Engelke, M. C., & Morton, S. J. (1995). Performance of three warm-season turfgrasses cultured in shade: Zoysiagrass. *Turf*, 95(11), 60-65.

Rimi, F., Macolino, S., Leinauer, B., & Ziliotto, U. (2011). Green-up of seeded bermudagrass cultivars as influenced by spring scalping. *HortTechnology*, 21(2), 230-235.

Severmutlu, S., Mutlu, N., Gurbuz, E., Gulsen, O., Hocagil, M., Karaguzel, O., Heng-Moss, T., Shearman, R. C., & Gaussoin, R. E. (2011a). Drought resistance of warm-season turfgrasses grown in Mediterranean region of Turkey. *HortTechnology*, 21(6), 726-736.

Severmutlu, S., Mutlu, N., Shearman, R. C., Gürbüz, E., Gülşen, O., Hocagil, M. M., Karagüzel, O., Heng-Moss, T., Riordan, T. P., & Gaussoin, R. E. (2011b). Establishment and turf qualities of warm-season turfgrasses in the mediterranean region. *HortTechnology*, 21:67–81.

Shareef, T. M. E., Ma, Z., & Zhao, B., (2019). Essentials of drip irrigation system for saving water and nutrients to plant roots: As a guide for growers. *Journal of Water Resource and Protection*, 11(09), 1129.

Trappe, J. M., Karcher, D. E., Richardson, M. D., & Patton, A. J. (2011). Shade and traffic tolerance varies for bermudagrass and zoysiagrass cultivars. *Crop Science*, 51, 870-877.

Wherley, B. G., Skulkaew, P., Chandra, A., Genovesi, A. D., & Engelke, M. C. (2011). Lowinput performance of zoysiagrass (*Zoysia* spp.) cultivars maintained under dense tree shade. *HortScience*, 46, 1033-1037.

White, C. B. (2003). The birth of a putting green. USGA Green Section Record. 41(6), 1-6.

Xie, Q., Niu, J., Xu, X., Xu, L., Zhang, Y., Fan, B., Liang, X., Zhang, L., Yin, S., & Han, L. (2015). De novo assembly of the Japanese lawngrass (*Zoysia japonica* Steud.) root transcriptome and identification of candidate unigenes related to early responses under salt stress. *Frontiers in Plant Science*, 6, 1-14.

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Use of plant indices in early yield estimation for winter wheat

Metin AYDOĞDU[1]*, Hakan YILDIZ[1]

[1]Soil Fertilizer and Water Resources Central Research Institute, Geographic Information Systems Center, Ankara, Türkiye

***Corresponding author e-mail:** metin.aydogdu@tarimorman.gov.tr

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Abstract: The study was carried out in İkizce Research Farm of Field Crops Central Research Institute in 2014 and 2015 . The experiment was established according to random blocks experimental design with three replicates and 0, 4, 8, 12 and 16 kg/da nitrogen applications were made. Normalized difference vegetation index (NDVI) readings were taken with a portable handheld GreenSeeker device throughout the growing season. Spectroradiometer readings were taken in each plot from sowing to harvest. In addition, the relationships between biophysical characteristics of the plant and yield values were determined. The measured spectroradiometer values were used to calculate various plant indices reported in the literature. Considering the phenological development periods between 2013 and 2014 in Haymana, the correlation values between grain yield and spectral indices (r^2 <0,277) in the early period (Feekes 1-9) from emergence to stalk emergence were lower than the values (r^2 <0,603) in the late period (Feekes 10-11,4). The correlation values of the first ten indices (SR-5, SR-8, NDI-2, OVI, SR-2, SR-17, NDVI-3, SR-10, NDI-1, NVI) in the late development period (flowering) ranged between R^2=0.453-0.603 and Green + Red + Red Border + Near Infra-Red (NIR) bands were prominent. The highest correlations between grain yield and spectral indices were determined at the beginning of flowering (26 May 2015) and correlation values ranged between R^2= 0.930-0.889 for the first ten indices for 2014-2015 growing season. The prominent indices in this period were NVI, SR-8, SR-11, SR-5, SR-17, OVI, SR-2, SR-1, ZTM, SR-16, respectively. These indices were in located in the 550-900 nm band range, in the green+red+red+red edge (Red Edge) + Near Infrared (NIR) range on the electromagnetic spectrum. The use of spectral data in early yield estimation in wheat is important in terms of guiding national agricultural policies. The application and dissemination of this estimation method in yield estimations in different locations in the future will provide great convenience.

Keywords: Wheat, indice, estimation, spectral reflectance, yield.

Kışlık buğday için erken dönem verim tahmininde bitki indekslerinin kullanımı

Öz: Çalışma 2014 ve 2015 yıllarında Tarla Bitkileri Merkez Araştırma Enstitüsü İkizce Araştırma Çiftliğinde yürütülmüştür. Deneme tesadüfi bloklar deneme desenine göre kurulmuş, üç tekerrürlü olmak üzere, 0, 4, 8, 12 ve 16 kg/da azot uygulamaları yapılmıştır. Bitki yetişme dönemi boyunca taşınabilir el GreenSeeker cihazı ile NDVI okumaları yapılmıştır. Her parselde ekimden hasada kadar gelişme peryodu boyunca spektroradyometre okumaları yapılmış, bunun yanısıra bitkinin biyofiziksel özellikleri ile verim değerleri arasındaki ilişkiler belirlenmiştir. Ölçülen spektroradyometre yansıma değerlerinden faydalanılarak literatürde verilen çeşitli bitki indeksleri hesaplanmıştır. Haymanada 2013 -2014 yılları arasında fenolojik gelişme dönemleri gözönüne alındığında çıkıştan sapa kalkmaya kadar olan erken dönemde (Feekes 1-9), dane verimi ile spektral indeksler arasındaki korelasyon değerleri (r <0,277), çiçeklenmeden danenin sararmasına kadar devam eden geç dönemdeki (Feekes 10-11,4) korelasyon değerlerine göre (r <0,603) düşük seyretmiştir. Geç gelişme döneminde (Çiçeklenme) öne çıkan ilk on indeksin (SR-5, SR-8, NDI-2, OVI, SR-2, SR-17, NDVI-3, SR-10, NDI-1, NVI) korelasyon değerleri R^2=0,453-0,603 arasında değişmiş ve Yeşil+Kırmızı+Kırmızı Sınır+Yakın Kızıl Ötesi bandlar ön plana çıkmıştır. 2014-2015 gelişme döneminde dane verimi ile spektral indeksler arasındaki korelasyonların en yüksek olduğu dönem çiçeklenme başlangıcı (26 Mayıs 2015) olarak belirlenmiş, korelasyon değerleri ilk on indeks için r= 0.930-0.889 arasında değişmiştir. Bu dönemde öne çıkan indeksler sırasıyla NVI, SR-8, SR-11, SR-5, SR-17, OVI, SR-2, SR-1, ZTM, SR-16 şeklinde sıralanmıştır. Bu indeksler 550-900 nm bant aralığında, elektromanyetik spektrum üzerinde yeşil+kırmızı+kırmızı sınır (Red Edge) +Yakın Kızıl Ötesi (NIR) aralıkta yer almıştır. Spektral verilerin buğday ‘da erken dönemde verim tahmininde kullanımı ülkesel tarımsal politikalara yön vermesi açısından önemlidir. Bu bakımdan gelecekte farklı lokasyonlarda rekolte tahminlerinde bu tahmin yönteminin uygulanması ve yaygınlaştırılması büyük kolaylıklar sağlayacaktır.

Anahtar kelimeler: Buğday, indeks, tahmin, spektral yansıma, verim.

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1. Introduction

The impact of the plant's environment and its growth may be assessed by vegetation indices, regardless of the growing environment. Plant water requirement, fertilization, climate and soil properties significantly alter the yield of crop plants. Crop simulation models mimic these inputs to estimate the expected yield in yield estimation for a specific region.Vegetation indices can determine the response of the plant to the environment without considering the complex relationships in plant growth. Normalised vegetation difference index (NDVI) is a widely used vegetation index. It was developed by Deering (1978). NDVI is related to the amount of nitrogen in the plant, chlorophyll content and green biomass. Plants absorb red (RED) wavelength light and use it for photosynthesis, so they reflect less in this region, while they reflect more near infrared (NIR) wavelength light. NDVI is calculated from the ratio of these two wavelength reflectance differences to their sum, i.e., NDVI = (NIR-RED) / (NIR+RED). Several studies have shown high correlations between vegetation indices derived from spectral observations and standard plant traits such as plant height, coverage and planting density number (Raun et al., 2005 and Stone et al., 1996). Vegetation indices are widely used in agriculture, because they allow fast and efficient detection of vegetation change and are easy to apply (Cattani et al., 2017). Studies have shown that plants show the most typical reflection in the NIR region (400-1100 nm). Therefore, spectro radiometric measurements in plants are concentrated in the NIR region (Başyiğit and Dinç, 2001).

Vegetation indices help to reveal the spectral reflectance characteristics of plants more clearly on green vegetation and help to eliminate negative effects caused by soil and other factors (Huete et al. 1985; Major et al. 1990). Spectral reflectance values provide a correlation between plant health and leaf biochemical concentration (Curran, 1989). Spectral indices can be measured on a single leaf of the plant or on a canopy. Values obtained from single leaf measurements neglect the influence of environmental conditions to a greater extent, while canopy measurements give larger scale values. Leaf-scale trials are rather used to obtain information on the chlorophyll concentration of whole branches from the biochemical concentration of the leaf from cellular reflections in plant tissues (Carter and Spiering, 2002). Gamon (1992) concluded that the use of multi-band indices is necessary to observe changes in plants rich in pigments such as carotenoids. These normalised index values are effectively used to reveal the biophysical parameters of plants using the spectral bands of vegetation (red and near infrared).

Reflectance values in the RED band range are inversely related to the amount of chlorophyll in plants, while reflectance values in the NIR infrared band range are directly related to leaf area (Tucker 1979). Spectral indices have been widely used in many agricultural applications to compare different growth patterns at field, regional and global scales (Elvidge and Chen, 1995). Geographical information systems are integrated with remote sensing technology to estimate bio-physical data and to measure plant biomass (Aparicio, et al., 2000). Raun et al. (2001), estimated the potential yield of winter wheat by spectral measurements after dormancy and to determine the relationship between the estimated yield and the actual yield in nine locations. The results indicated that there was a significant relationship between the yield calculated from the readings made at Feekes 4-5 (ZD 31) and the actual yield at the level of (r = 0.50**). Spectral vegetation index (NDVI) measurements made in wheat in the early period can help to calculate the differences in the light utilization capacity of genotypes as well as differences in their biomass can be calculated. This value (NDVI) also gives an idea about the photosynthetic capacity in relation to the total chlorophyll content in the biomass (Gutierrez-Rodriguez et al. 2004). Another environmental factor determining plant yield is cumulative temperature. The correlation between phenologically calculated growing degree days GDD and NDVI (Normalised Difference Vegetation Index) data during the growing season is very high (Karlsen et al., 2005). Raun et al. (2001), found that spectral measurements (NDVI) at different growth stages of winter wheat have a very significant relationship with total biomass in determining yield potential. Vegetation indices have been used to increase crop production and reduce the environmental burden of agriculture. Easy-to-use and effective measuring devices have been developed for vegetation index measurement, especially for nitrogen fertilizer applications. Nitrogen is the limiting nutrient for crop production and has the greatest impact on grain. Five different nitrogen doses (0, 4, 8, 12, 16 kg/da) were applied in three replicates according to the coincidence blocks experimental design. In each plot, spectroradiometer readings were taken throughout the growth period from sowing to harvest, and the relationships between biophysical characteristics of the plant and yield values were determined. The measured spectroradiometer values were used to calculate various plant indices reported in the literature. The correlations of these indices values with yield and other biophysical parameters were examined, and the behavior of these indices in different phenological development periods (early-late-all) and fertilizer doses were investigated. In conclusion, the main objective of this study was to investigate the usefulness of hyperspectral data for early yield prediction in winter wheat and to determine which plant indices and which band regions are effective for this purpose.

2. Material and Method

2.1. Plant material

The project was carried out in the production farm of the Central Research Institute of Field Crops in İkizce, Haymana district of Ankara in 2013-2014 and 2014-2015 growing seasons. İkizce winter wheat cultivar was used in the study. The experiment was established according to random blocks experimental design and five different nitrogen doses, i.e., 0, 4, 8, 12 and 16 kg N/da were used with three replications. Biophysical observations and NDVI readings were taken seven times during the growing period of both years. A portable GreenSeeker device was used to follow the vegetation development of the plant in the field.

2.2. Climate and soil characteristics of the experimental site

The farm has been established in the south-west of Ankara where continental climate prevails, with dry and hot summers and cold and rainy winters. The experiment was carried out in İkizce/Haymana Research and Application Farm of the Central Research Institute of Field Crops (Figure 1). The test area is between 39‘ 12‘‘ -43’ 6‘‘ north latitude and 35‘ 58‘‘ -37’ 44‘‘ east longitude.

Figure 1. Haymana-İkizce production enterprise and experiment area.

2.3. Climatic characteristics of the research site

The average annual temperature of the area is 10.0 ºC according to the 20-year data of İkizce station. The average highest temperature is 18.5 °C in August and the average lowest temperature is -5.2 °C in January. Total annual rainfall totals is 398.7 mm. The wettest month is December with 53.8 mm and the driest month is August with 13.8 mm. precipitation.

2.4. Soil characteristics of the research site

The soil of İkizce farmlands belong to the brown soil group. The soil texture is generally medium heavy and the lime content in the soil is high (25-45 %). The amount of organic matter in the soil is approximately 1 % and pH is around 7,5. The slope of the land varies between 2-15%. The altitude of the area where the meteorological station is located in the farm is 1070 m.

2.5. Experimental design

The experiment was started in Haymana with the preliminary trial results obtained in 2012-2013 for the first year. Afterwards, it was continued with the data collected on the experimental plots established in Haymana during 2013-2014 and 2014-2015. The experiment was carried out by applying different nitrogen doses to each plot on the plots formed according to the random blocks experimental design with three replications. Five different 0-4-8-12-16 kg/da pure nitrogen doses were used in each replicate. The experimental area consists of a total of 15 plots (3.15 m x 10 m = 31.5 m^2). Twenty (20) kg seeds of

İkizce wheat variety per decare was sown with 24-row pneumatic seeder keeping row spacing of 13 cm. Half of the plot length determined for each plot was reserved for agronomic sampling (% cover, LAI calculation, wet-dry biological mass per m^2, etc.). The remaining half (5 m) was allocated for the calculation of grain yield. For the collection of biomass data, 0.25 m^2 quadrate (0.50m x 0.50m) was used. Plant samples in the quadrate were were harvested, weighed fresh and then dried in an oven at 70-80 ^oC for 3-4 days and calculated as kg/ha.

2.6. Fertilization and sampling dates

In the experiment, 5.5 kg P_2O_5/da (DAP 18-46%) and 12 kg/ha DAP base fertilizer was applied to the soil before sowing and 0.378 kg/ 31.5 m^2 DAP fertilizer was applied for each plot. Ammonium nitrate (33%) nitrogen fertilizer (0-0.176-0.557-0.557-0.939-1.321-1.321- kg/31.5 m^2) was applied in addition to the plots for 5 different nitrogen doses (0-4-8-12-16 kg/da) in the experiment established with three replicates as top dressing in early spring. Fertilizer applications were applied by subtracting nitrogen provided by DAP. All phosphorus was applied at planting, whereas half of the nitrogen was applied at planting, and the remaining half was applied as top dressing at the end of the tillering period in spring. Sampling times of 2013-2014 and 2014-2015 were determined according to phenological periods (Table 1, 2).

Table 1. Number and dates of sampling according to different growth stages (Zadoks) in Haymanada during 2013-2014 vegetation period.

Phenological Period (2013-2014) Date	Cultivar	Sampling Periods *(Feekes)*	Number of Samples	Zadoks Scale
19 March2014	İkizce	Emergence (1)	6	10-19
26 March 2014	İkizce	Tillering (2)	16	21-25
3 April 2014	İkizce	End of Tillering (3)	15	26-29
22 April 2014	İkizce	Beginning of Jointing (4-5)	15	30
13 May 2014	İkizce	Jointing (6-7)	15	31-39
22 May 2014	İkizce	Emergence of the Flag Leaf (8-9)	16	40-69
26 May 2014	İkizce	Beginning of flowering (10)	16	
4 June 2014	İkizce	Beginning of the Milk Period (11)	16	70-77
12 June 2014	İkizce	Dough Formation Period of Grain, (11.2)	16	80-87
24 June 2014	İkizce	Hardening, ripening and yellowing of the grain (11.3-11.4)	16	91-92
		Total Number of Samples	147	

Table 2. Number and dates of sampling according to different growth stages (Zadoks) in Haymanada during 2014-2015 vegetation period.

Phenological Period (2014-2015) Date	Cultivar	Sampling Periods (Feekes)	Number of Samples	Zadoks Scala
18 March 2015	İkizce	Emergence ((1-2)	-	10-19
06 April 2015	ikizce	End of Tillering (3)	16	26-29
17 April 2015	İkizce	Beginning of Jointing (4-5)	16-	30
30 April 2015	İkizce	Jointing (5)	16	26-29
12 May 2015	İkizce	Jointing (6-7)	16	31-39
26 May 2015	İkizce	Beginning of flowering (8-10)	16	40-69
10 June 2015	İkizce	Beginning of the Milk Period (11)	16	70-77
07 July 2015	İkizce	Hardening, ripening and yellowing of the grain (11.3-11.4)	16	80-92
		Total Number of Samples	128	

2.7. Collection and evaluation of hayperspectral data

Spectroradiometric canopy reflectance measurements were made using a portable handheld spectroradiometer between 11 am and 15 pm, when the sun's rays were perpendicular to the earth's surface and cloudless. Spectral reflections in the plant leaves were carried out with the help of the spectral sensor band range from 350 nm to 1150 nm every 3 nm. The measurements were instantly transferred to the computer with cable connection. Measurements were taken from a height of 70 cm at an angle of 25^0 ' to the earth's surface.

Measurements were taken at 8 different phenological periods. These measurements were then averaged and used in the calculation. Using the reflection values, the vegetation index values given in the appendix were calculated and their correlation with yield was revealed (Table 3).

Table 3. Indices used in yield estimation in the project

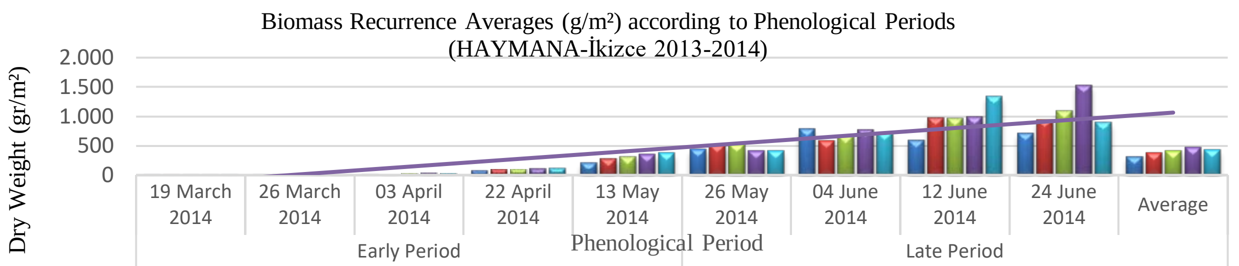
Structural Indices		Chlorophyll Pigment Indices		Red Edge Indices
SR1	NDVI13	NDI5	SRPI (Simple Ratio Pigment Index)	Red Edge 750~700
SR2	NDVI14	NDI9	RVI (Ratio Vegetation Index)	Red Edge 740~ 720
SR4	NDVI16	NDVI1	RDVI (Renormalized Difference Vegetation Index)	ZTM (Zarco Tejada and Miller)
SR5	NDVI17	NDVI2	MCARI2	
SR7	NDVI18	NDVI3	TVI (Triangular vegetation Index)	
SR5	NDVI(Modis)	NDVI4	LCCI (Leaf and Canopy Chlorophyll Index)	
SR8	HNDVI	NDVI5	NVI (New Vegetation Index)	
SR9	SR11	NDVI6	DVI (Difference Vegetation index)	
SR10	SR14	NDVI11	OVI (Optimum Vegetation İndex)	
SR11	SR16	NDVI12	HVI	
SR14	SR17	NDVI13	NVI	
SR16	MTVI	NDVI14	ARI	
NDVI	SR17	NDVI16	NPCI	
NDI1	SAVI (Soil Adjusted Veg. Index)	NDVI17	ARI	
NDI2	MSAVI	NDVI18	SIPI (Structural insensitive Pigment index)	
NDI3	OSAVI (Optimized SAVI)		GREEN INDEKS	
NDI4	TCI/OSAVI		PSRI	
NDI9	MSR		PRI	
NDI10	SR8		PhRI	

3. Results and Discussion

3.1. Relationship between yield (biological yield) and spectral indices

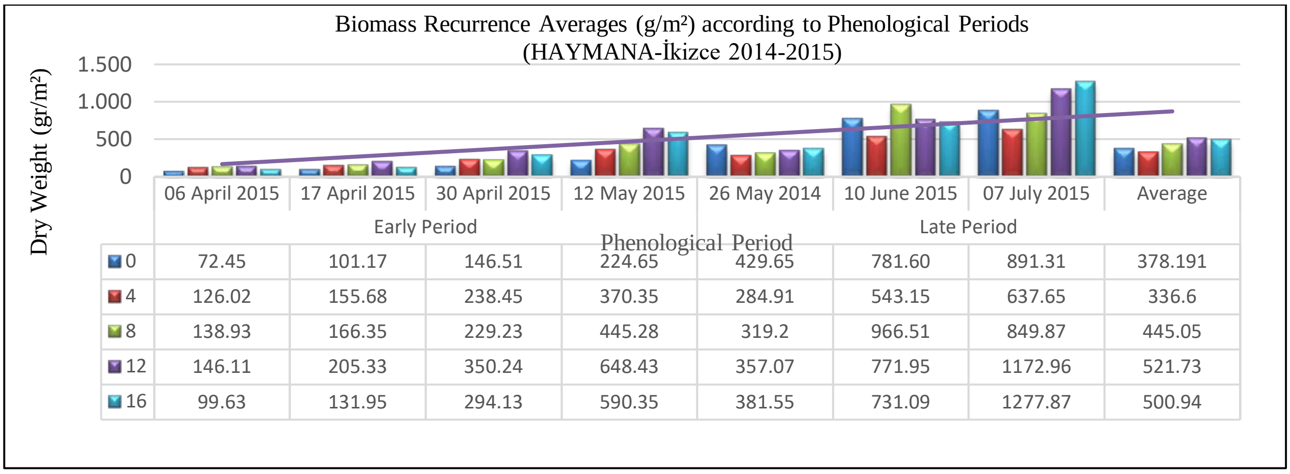
Analysis of biomass variation over the plant growth period (Haymana 2013-2014) revealed that biomass increased from the early to the late period in correlation with the increasing nitrogen dose. The highest amount of biomass (1538.51 g/m^2) was observed at 12 kg/da N dose in the late period (Figure 2). In the 2014-2015 growth period, the highest biomass was noted for 16 kg/da N dose in the late period (1277.87 g/m^2) (Figure 3).

Correlation (r) analysis between wheat biomass (ton/da) and single band reflectance values (at 3 nm wavelength) during the 2013-2014 growth periods revealed significant correlation between biomass and wavelengths within the 409-549 nm range in the visible spectrum (Feekes 4-7) and in the red edge region (700-770 nm), particularly during the early, late, and overall growth phases. During the late period (Feekes 8-10), an increased correlation was noted in the wavelength range of 530-680 nm within the visible spectrum. Conversely, a negative change in correlation was recorded in the red edge region (700-750 nm), while non-significant correlation was observed in the near-infrared region (750-1000 nm). Throughout the whole duration (Feekes 4-10), the most significant change in correlation was seen in the red edge spectrum (Red Edge 700-750 nm) (Figure 4).



	19 March 2014	26 March 2014	03 April 2014	22 April 2014	13 May 2014	26 May 2014	04 June 2014	12 June 2014	24 June 2014	Average
0	6.733	9.73	14.05	76.32	209.31	447.04	787.47	602.88	723.15	319.631
4	5.02	10.61	23.73	98.45	284.91	520.43	594.99	977.97	947.04	384.794
8	8.01	14.16	26.43	98.37	319.2	524.8	672.16	974.08	1097.07	414.92
12	5.82	19.41	34.51	112.21	357.07	417.12	771.95	998.93	1538.51	472.837
16	11.367	23.52	26.69	117.39	381.55	419.89	731.09	1342.4	904.32	439.802

Figure 2. Variation in biomass of wheat according to the amount of nitrogen applied and phenological development period in 2013-2014 (gr / m^2).



	06 April 2015	17 April 2015	30 April 2015	12 May 2015	26 May 2014	10 June 2015	07 July 2015	Average
0	72.45	101.17	146.51	224.65	429.65	781.60	891.31	378.191
4	126.02	155.68	238.45	370.35	284.91	543.15	637.65	336.6
8	138.93	166.35	229.23	445.28	319.2	966.51	849.87	445.05
12	146.11	205.33	350.24	648.43	357.07	771.95	1172.96	521.73
16	99.63	131.95	294.13	590.35	381.55	731.09	1277.87	500.94

Figure 3. Variation in biomass of wheat according to the amount of nitrogen applied and phenological development period in 2014-2015 (gr / m^2)

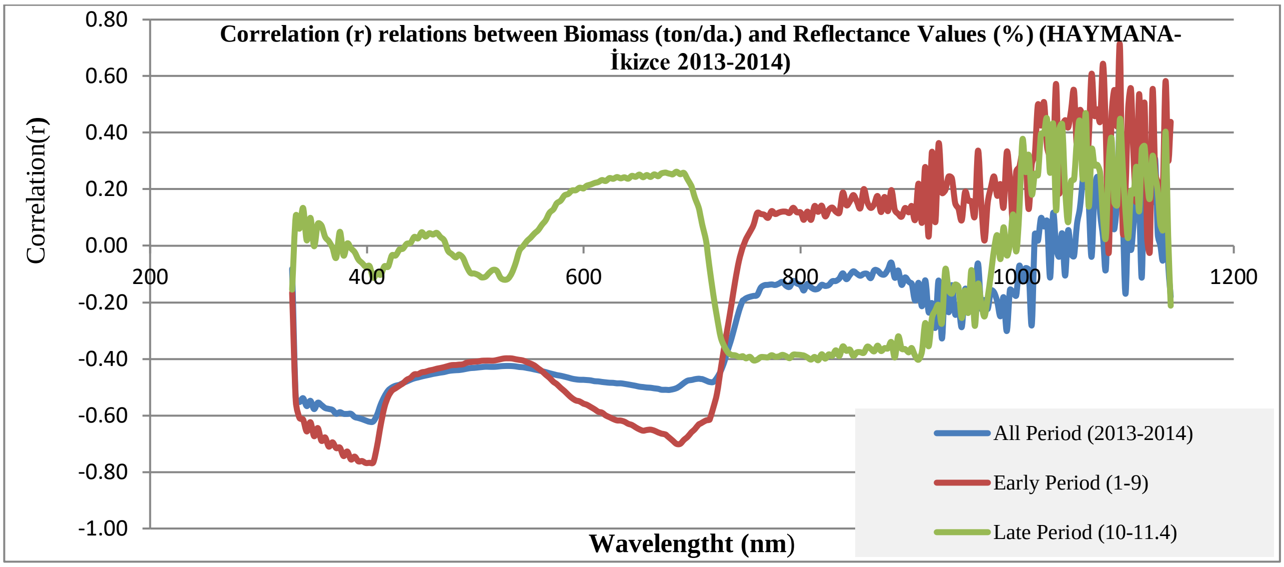


Figure 4. The correlation (r) relations between Biomass (ton/da) and single band reflectance values (3 nm) in wheat in 2013-2014.

3.2. Relationships between grainyield and spectral indices (2013-2014)

Relationships between grain yield-spectral indices for different phenological periods in Haymana 2013-2014 period indicated the highest correlation for flowering period (26 May 2014), stalk emergence period (13 May 2014) and milking period (04 June 2014), respectively. The prominent indices in these periods are SR-5 (650-700), SR-8 (550-860), NDVI-6 (708-760), NDVI-2 (700-800), Red Edge (720-740), SR-4 (720-740), LCCI (705-750). Green+Red+Red Edge+Near Infrared (NIR) bands have come to the fore to be used in yield estimation (Table 4). Considering the phenological development periods, the correlation values (r= 0.277) between grain yield and spectral indices in the early period from emergence to stalk emergence (Feekes 1-9) were lower than the correlation values (r = 0.603) in the late period from flowering to yellowing of grain (Feekes 10-11,4). The correlation values of the first ten indices (SR-5, SR-8, NDI-2, OVI, SR-2, SR-17, NDVI-3, SR-10, NDI-1, NVI) which were prominent in the late development period (Stalk emergence+Blooming+Milk maturity+Grain setting) varied between r =0.453-0.603 and Green + Red+ Red border + NIR bands were prominent. Correlations in the late period were found to be higher than in the other periods.

The correlation between grain yield and spectral indicators across several phenological phases revealed the strongest correlation values during the flowering period on 26 May 2014 (Figure 5).

Table 4. Grain yield-index relationships according to different development periods (Early-Late-All Periods) (Haymana-2013-2014).

Early Period		Late Period		All Period	
Indices	*r*	*Indices*	*r*	*Indices*	*r*
Red Edge (740-720)	0.277	SR-5	0.603	SR-8	0.348
SR-4	0.277	SR-8	0.581	SR-5	0.347
SR-9	0.255	NDI-2	0.571	Red Edge (740-720)	0.325
ZTM	0.254	OVI	0.507	SR-4	0.325
SR-16	0.252	SR-2	0.494	NVI	0.320
SR-5	0.242	SR-17	0.483	ZTM	0.313
TVI	0.239	NDVI3	0.464	OVI	0.311
Red Edge (750-700)	0.237	SR-10	0.461	SR-16	0.308
HVI	0.237	NDI-1	0.460	SR-9	0.303
SR-8	0.236	NVI	0.453	SR-17	0.281

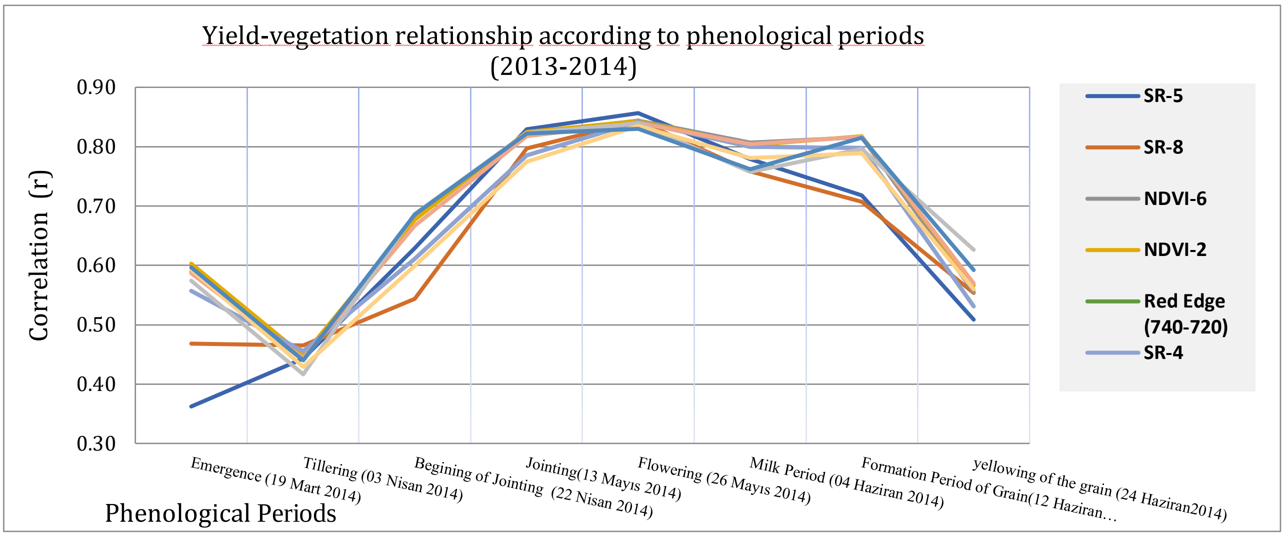


Figure 5. Fenolojik dönemlere göre verim-vejetasyon indeks ilişkisi (2013-2014).
SR-5 (650-700 nm.) Red+Red Edge, SR-8 (550-860 nm.) Green+Red+Near Infrared, NDVI-6 (708-760 nm.) Red Edge, NDVI-2 (700-800 nm.) Red Edge+ Near Infrared, Red Edge (740-720 nm.) Red Edge

The correlation values between the top ten prominent indices in this period ranged between r = 0.857-0.835. The prominent indices during this period were SR-5 (650-700), SR-8 (550-860), NDVI-6 (708-760), NDVI-2 (700-800), NDI-1 (715-747), Red Edge (740-720), SR-4 (740-720), LCCI (750-705), NDVI-3 (780-550) and ZTM (750-710). Effective spectral band regions for yield estimation were found to be Red+Red Edge (Red Edge)+Near Infrared (NIR). This period was followed by the Staggering period (13 May 2014), and the correlation values of the top ten indices in this period ranged between r = 0.849-0.813. The prominent indices in this period are NDI-2, NDI-1, SR-5, NDVI-2, NDVI-3, NDVI-6, NDVI-4, OSAVI, SIPI, NDVI(Modis), NDVI, SAVI. The correlation values between the first nine prominent indices during the Hardening Period (12 June 2014) ranged between r = 0.847-0.791. The prominent indices in this period were MSAVI, SAVI-1, NDVI-5, NDVI-2, NDVI-6, NDVI-4, RDVI, NDVI-3, OVI, NDVI-1. The correlation values between the top ten indices during the milking period (04 June 2014) ranged between r = 0.796-0.886. The prominent indices in this period were SRPI, OVI-1, NDI-2, NDVI-6, NDI-1, LCC, NDVI-2, Red Edge (740-720), SR-4, SR-14.

3.3. Relationships between yield and spectral indices (Haymana 2014-2015)

Correlation (between biomass (ton/da) and single band reflectance values (at 3 nm wavelength) indicated an increasing correlation in 530-680 nm band range. A negative decrease in the correlation was noted in the red region (Red Edge 700-750 nm), and no significant change in correlation was observed in NIR region (Figure 6). Considering different phenological periods, the highest biological yield values were found in the late period (10 June 2015) at 12 kg/da nitrogen dose. High correlation values were found in the blue band (400-500 nm.) green and red bands (570-680 nm.). High correlation values were found in the green and red band range (570-680 nm) in the early period (06 April-12 May 2015).

3.4. Relationships between grainyield and spectral indices (2014-2015)

Correlations between grain yield and spectral indices for different phenological periods during 2014-2015 indicated the highest correlation during the flowering period (26 May 2015), milking period (10 June 2015), stalk emergence period (12 May 2015), respectively (Table 5). The prominent indices in these periods were NVI(673-777), SR-8(550-860), SR-11(680-900), SR-5(650-700), SR-17 (560-810), OVI(730-760), SR-2(550-800), SR-1(670-801), ZTM(710-750), SR-16(705-750). Green + Red + Red Edge + NIR bands have come to the fore for use in yield estimation (Figure 10). Relationships between grain yield-spectral indices according to different phenological periods indicated the highest correlation during flowering period (26 May 2015) (Figure 7).

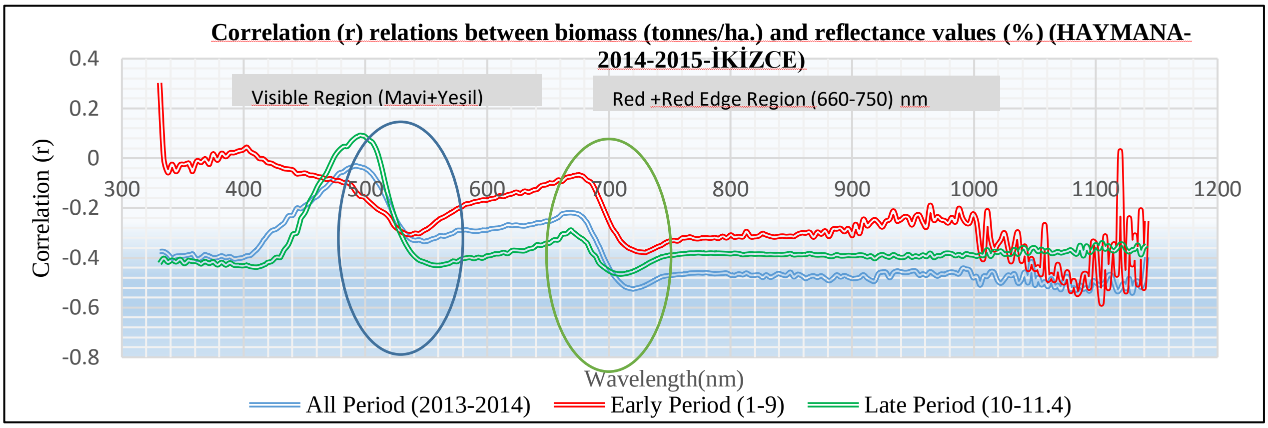


Figure 6. Correlation (r) relations between biomass (ton/da) and single band Reflectance Values (3 nm wave Saturation) in wheat (Haymana-2014-2015-İkizce).

Table 5. Correlations between grain yield and spectral indices and prominent indices during flowering period (Haymana 2014-2015).

Agronomic Properties	Indices	Band Range (nm.)	Correlation (r)	Determination Coefficient (R^2)	Regression Equation (26 May 2015)
Yield (kg/da)	NVI	673-777	0.964	0.930	Y= 0.0048X-0.4588
	SR-8	550-860	0.956	0.914	Y = 0.0015X- 0.0864
	SR-11	680-900	0.952	0.907	Y = 0.0305X + 0.1288
	SR-5	650-700	0.951	0.905	Y = 0.0002x + 0.0136
	SR-17	560-810	0.947	0.898	Y = 0.0199X + 0.4413
	OVI	730-760	0.946	0.895	y = 0.0017x + 0.9336
	SR-2	550-800	0.945	0.894	y = 0.0203x + 0.4963
	SR-1	670-801	0.945	0.893	Y= 0.0393x - 0.5
	ZTM	710-750	0.944	0.891	Y = 0.008x + 0.6097
	SR-16	705-750	0.943	0.889	Y = 0.0107x + 0.4741

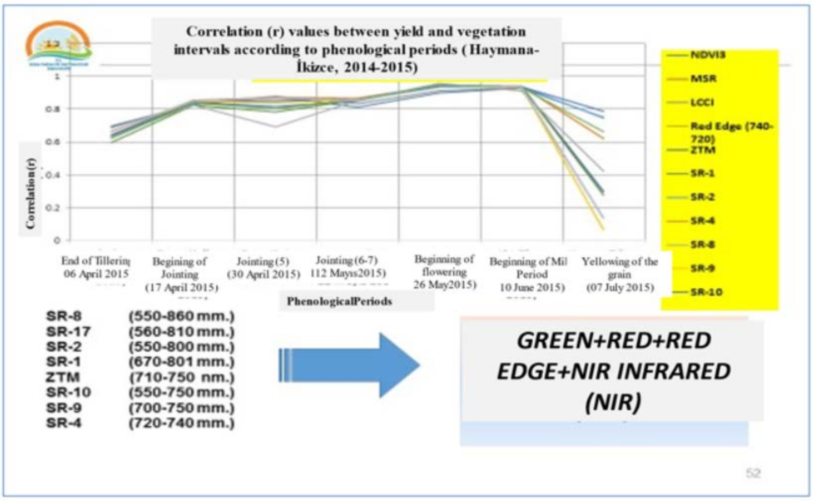


Figure 7. Yield-vegetation index relationship according to phenological periods (2014-2015)

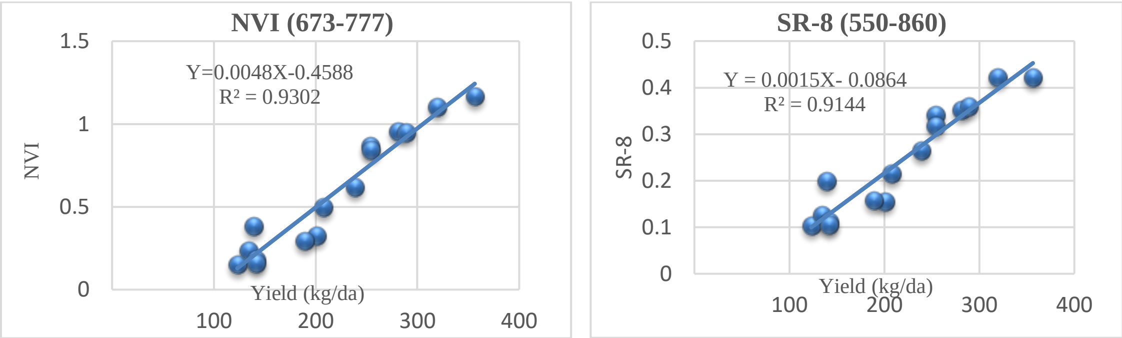


Figure 8. Spectral indices for predicting grain yield (2014-2015)

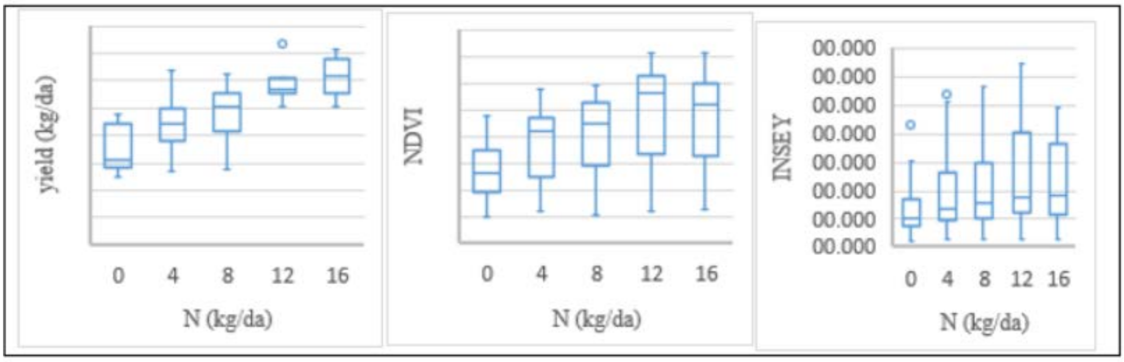


Figure 9. Yield, NDVI, INSEY values at different nitrogen doses.

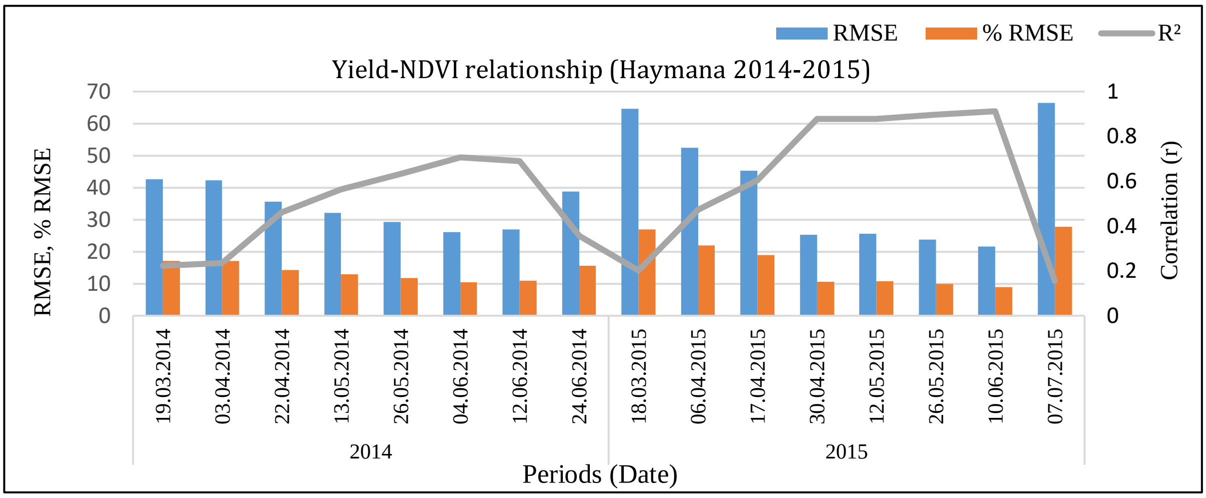


Figure 10. Yield-NDVI relationship (Haymana 2014-2015).

Correlation between grain yield and vegetation index between 2014-2015 indicated an increase from the tillering period (06 April 2015) until the middle of the milking period. However, the highest correlation values were found in the middle of the flowering period (26 May 2015), similar to the 2013-2014 (r = 0.943-0.964). In this case, the band ranges to be taken as a basis for early yield estimation were determined as the region within the red (Red), red edge (Red Edge) and early NIR bands. As a result, spectral indices (NVI, SR-8, SR-11, SR-5) and their regression estimation equations were obtained using these bands in early yield estimation. In the study, regression equations were used to reveal the relationships between actual yields and estimated yields calculated from the indices. In this way, indices and effective band regions that can be used in yield estimation were revealed.

3.5. Yield-NDVI-INSEY relationships according to different phenological periods in wheat

The difference in yield NDVI and INSEY values obtained from the plots in 2014 and 2015 by applying different nitrogen doses are given in the Box-Whisker plot (Figure 9).

The relationship graphs between NDVI measurements two years vegetation period and the calculated INSEY values and yields are shown in Figure 12. It is observed that the relationship between INSEY and yield is higher in 2015 than in 2014. The relationship between INSEY and yield increases during the periods when plant height increased, and soil coverage of the plant increased during the year. This relationship is lowest in March, increases in April and May, and reached its highest level in late May and early June. This relationship decreases towards the end of June when the plant starts to turn yellow. The response of the plant to the applied nitrogen is an important criterion to evaluate the nitrogen requirement of the plant to obtain maximum yield (Fageria and Baligar 2005). The relationship between NDVI and yield is further increased by dividing NDVI by GDD (GDD=[(Tmin+Tmax)/2-4.4 °C]), which is measured from the sowing date throughout development (Lukina et al., 2001). In the relationship between NDVI and yield, the highest yield values were found on 04 June 2014 (r = 0.707, RMSE=26.08, % RMSE=10.51) in 2014 and on 10.06.2015 (r = 0.912, RMSE=21.55, % RMSE=8.99) in 2015 (Figure 10). The correlations between biophysical characteristics (biomass, grain yield) influencing plant growth and various vegetation indices (NDVI, DVI, RVI, MTVI, OSAVI, etc.) derived from spectral reflectance values collected through ground measurements of plants within the 330-1142 nm range were investigated, and regression prediction equations were developed for predicting agronomic characteristics across different phenological development stages. The impact of varying nitrogen fertilizer doses on the spectral reflectance characteristics of wheat during different growth stages was determined, and the optimal spectral band combinations, band intervals, and timing of nitrogen application, which directly influence yield, were determined. Correlation (r) relations between single band reflectance values (at 3 nm wavelength) and biomass (ton/da.) were analyzed, high correlation values were observed between biomass and wavelengths in the band range of 409-549 nm in the visible region (Feekes 4-7) and in the red edge region (700-770 nm), especially in the early period (Feekes 4-7), considering the early, late and the whole development period. In the late period (Feekes 8-10), an increasing correlation was observed in the band range 530-680 nm. in the visible region, a negative decrease in the correlation was observed in the red edge region (Red Edge 700-750 nm), and no significant change in the correlation was observed in the near infrared region (NIR) with a wavelength of 750-1000 nm Considering the whole period (Feekes 4-10), the highest correlation change was observed in the red edge region (Red Edge 700-750 nm). Relationships between agronomic traits and spectral indices were analyzed in 2014-2015 vegetation period. The relationships between the index values calculated according to the period when the spectral readings were taken, and biomass and yield were analyzed. When the Correlation (r) relations between Biomass (ton/da.) and Single band Reflectance values (at 3 nm) of wheat in Haymanada İkizce experimental area according to different development periods in 2014-2015, it was observed that there was an increasing correlation in the visible region in the 530-680 nm band range in the visible region, a negative decrease was observed in the correlation in the red region (Red Edge 700-750 nm), and no significant change was observed in the correlation in the near infrared region (NIR) with a wavelength of 750-1000 nm Considering different phenological periods, the highest biological yield values were found at 12 kg/da nitrogen dose in the late period (10 June 2015). Especially considering the late and the whole development periods, high correlation values were found in the blue band range (400-500 nm) in the visible region and in the green and red bands range (570-680 nm) in the visible region. The highest correlations between biomass (kg/ha) and spectral indices were determined at tillering (06 April 2015) and stalk emergence (12 May 2015), and correlation values ranged between R^2= 0.771-0.735 for the first ten indices. The prominent indices in this period were NDI-2, SR-11, SR-17, SR-9, ZTM, SR-1, SR-16, OVI-4, SR-10 and NDVI-2. These indices were in the 550-900 nm band range, in the green + red + red edge (Red Edge) + NIR range on the electromagnetic spectrum. When the relationships between grain yield-spectral indices for different phenological periods in Haymana 2014-2015 period were examined, the highest correlation values were found in flowering period (26 May 2015), milking period (10 June 2015) and stalk emergence period (12 May 2015), respectively. The prominent indices in these periods are NVI (673-777), SR-8 (550-860), SR-11 (680-900), SR-5 (650-700), SR-17 (560-810), OVI (730-760), SR-2 (550-800), SR-1 (670-801), ZTM (710-750), SR-16

(705-750). Green+Red+Red Edge+Near Infrared (NIR) bands have come to the forefront to be used in yield estimation. These results obtained at Haymana location showed that the spectral readings obtained during the flowering period of winter wheat and the indices and yield estimation equations obtained by using the spectral band combinations related to them can be used for yield estimation in Ankara province conditions.

4. Conclusion

The growth stage of the plant has gained importance for future research. It will be aimed at which nitrogen fertilizer application is necessary for the highest yield at which stage of the plant. Nowadays, many hyperspectral vegetation indices have been developed to determine yield estimate in wheat. However, many of them are still under evaluation and need to be re-tested in different locations according to different growth stages of the plant, and years

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Conflict of interest

The authors declare no conflicts of interest.

Authorship contribution statement

M.A: Investigation, methodology, conceptualization. H.Y: Validation, formal analysis, writing - original draft.

References

Aparicio, N., Villegas, D., Casadesus, J., Araus, J. L. & Royo, C. (2000). "Spectral Vegetation Indices as Nondestructive Tools for Determining Durum Wheat Yield." *Agronomy Journal* 92(1): 83-91.

Başayiğit, L, & Dinç, U., (2001). Toprak Etüd ve Haritalama Çalışmalarında Bilgisayar Teknolojilerinin Kullanımı, Tarımda Bilişim Teknolojileri 4. Sempozyumu,Sütçüimam Üniversitesi, Kahramanmaraş, s 283-291.

Cattani, C. E., Garcia, M. R., Mercante, E., Johann, J. A., Correa, M. M., & Oldoni, L. V. (2017). Spectral-temporal characterization of wheat cultivars through NDVI obtained by terrestrial sensors. *Revista Brasileira de Engenharia Agrícola e Ambiental*, *21*(11), 769-773. http://dx.doi.org/10.1590/1807-1929/agriambi.v21n11p769-773

Carter, G.A., & Spiering. B.A. (2002). Optical properties of intact leave for estimating chlorophyll concentration. *J. Environ. Qual.* 31:1424-1432.

Curran, P.J. (1989). Remote sensing of foliar chemistry. Remote Sens. Environ. 30:271-278.

Deering, D. W. (1978). Rangeland reflectance characteristics measured by aircraft and spacecraft sensors. Ph. D Dissertation. Texas A&M Universtiy.

Fageria, N. K., Baligar, V. C., & Bailey, B. A. (2005). Role of cover crops in improving soil and row crop productivity. *Communications in soil science and plant analysis*, *36*(19-20), 2733-2757.

Elvidge,C.D., & Chen, Z. (1995). Comparison of broad-band and near-infrared vegetation indices.*Remote Sensing of Environment*,54,pp.38-48.

Gamon, J.A., J. Penuelas, & C.B. Field. (1992). A narrow-waveband spectral index that tracks diurnal changes in photosynthetic efficiency. *Remote Sens. Environ*. 41:35-44.

Gutierrez-Rodriguez, M., Reynolds, M.P., Escalante-Estrada, J.A., & Rodriguez-Gonzalez, M.T., (2004), Association between canopy reflectance indices and yield and physiological tarits in bread wheat under drought and well-irrigated conditions, *Australian J. of Agron. Res*. 55:1139-1147.

Huete, A.R., R.D. Jackson, & D.F. Post. (1985). Spectral response of a plant canopy with different soil backgrounds. Remote Sens. Environ. 17:37-53.

Justes, E., Mary, B., Meynard J.M., Machet, J.M., & Thelier-Huche, L., (1994). Determination of a critical nitrogen concentration dilution curve for winter wheat. *Crops Ann.Bot*.74,397-407.

Karlsen, S. R., Elvebakk, A., Høgda, K. A., Johansen, B., & Beck, P. S. A. (2005). GIMMS-NDVI based mapping of the growing season and bioclimatic zones in Fennoscandia and neighbouring parts of NW Russia. In *Proceeding (extended abstract) for the 31st International Symposium on Remote Sensing of Environment (IRSE)* (pp. 20-24).

Lukina, E. V., Freeman, K. W., Wynn, K. J., Thomason, W. E., Mullen, R. W., Stone, M. L., & Raun, W. R. (2001). Nitrogen fertilization optimization algorithm based on in-season estimates of yield and plant nitrogen uptake. *Journal of plant nutrition*, *24*(6), 885-898.

Major, D.J., F. Baret, & G. Guyot. 1990. A ratio vegetation index adjusted for soil brightness. Int. *J. Remote Sens.* 11:727-740.

Raun, W.R., Solie, J.B., Johnson, G.V., Stone, M.L., Lukina, E.V., Thomason, W.E., & Schepers, J.S., (2001), In-season prediction of potential grain yield in winter wheat using canopy reflectance, *Agron.* J. 93:131–138.

Raun, W. R., Solie, J. B., Stone, M. L., Martin, K. L., Freeman, K. W., Mullen, R. W., & Johnson, G. V. (2005). Optical sensor-based algorithm for crop nitrogen fertilization. *Communications in Soil Science and Plant Analysis*, *36*(19-20), 2759-2781.

Stone, M. L., Solie, J. B., Raun, W. R., Whitney, R. W., Taylor, S. L., & Ringer, J. D. (1996). Use of spectral radiance for correcting in-season fertilizer nitrogen deficiencies in winter wheat. *Transactions of the ASAE*, *39*(5), 1623-1631.

Tucker, C.J. (1979). Red and photografic infrared linear combination for monitoring vegetation.*Remote Sensing of Environment*,8 (1), 27-150.

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Evaluation of basic soil characteristics of Turkish forests using GIS

Hüseyin SARI[1]*, Mikayil ÖZTÜRK[2]

[1]Tekirdağ Namık Kemal University, Faculty of Agriculture, Department of Soil Science and Plant Nutrition, Tekirdağ, Türkiye
[2]Tekirdağ Namık Kemal University, Institute of Natural and Applied Sciences, Department of Soil Science and Plant Nutrition, Tekirdağ, Türkiye

***Corresponding author e-mail: hsari@nku.edu.tr**

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Abstract: Riparian forests (or floodplain forests) are rare ecosystems with a variety of habitats resulting from the temporal and spatial variation in the relationship between the water level of rivers and the geomorphological characteristics of floodplains. Turkey is one of the countries with floodplain forest ecosystem characteristics. These forests, protected under various status are significant for biodiversity. Although many studies have been carried out on the forest cover, vegetation, landscape characteristics and tourism potential of Turkey's floodplain forests, little research has been carried out on the basic soil characteristics. However, it is very important to explain the basic soil properties for evaluating the existing floodplain forest ecosystem in a sustainable way. The aim of this study was to evaluate the basic soil properties of Turkey's riparian forests using GIS. In this context, firstly, 9 floodplain forests reported in the literature and their boundaries were identified. These were Acarlar, Hacıosman (Meşeligöl), Hendek-Süleymaniye, İğneada, Karacabey, Köyceğiz, Sarıkum, Sinop-Aksaz and Yörükler (Galeriç) floodplain forests. The basic soil characteristics within the boundaries of these flooded forests were described using GIS techniques. The basic soil properties were extracted from the data of the National Soil Information System provided by the General Directorate of Agricultural Research and Policies. According to the results of the study, alluvial soils are generally widespread in the flooded forests connected to river systems. When evaluated in terms of land use, the largest class of floodplain forests is woodland. When evaluated in terms of land capability class, class II, III and VII soils are the areas that generally characterize the flooded forests.

Keywords: Alluvial forest, GIS, soil, land use, land capability class.

Türkiye'nin subasar ormanlarının temel toprak özelliklerinin CBS ile değerlendirilmesi

Öz: Subasar (longoz) ormanlar (veya taşkın yatağı ormanları), akarsuların su seviyesi ve taşkın yataklarının jeomorfolojik özellikleri arasındaki ilişkinin zamansal ve mekânsal değişikliği sonucunda ortaya çıkan çeşitli habitatların bulunduğu nadir ekosistemlerdir. Türkiye'de subasar ormanların görüldüğü ekosistem özelliklere sahip olan ülkelerden birisidir. Farklı statülerde koruma altına alınmış olan bu ormanlar, biyoçeşitlilik açısından önemlidir. Daha önce Türkiye'nin subasar ormanlarının genellikle orman varlığı, bitki örtüsü, peyzaj özellikleri ve turizm potansiyeline yönelik çok çeşitli çalışmalar yapılmasına rağmen temel toprak özellikleri konusunda çok sınırlı sayıda araştırma yapılmıştır. Ancak mevcut subasar orman ekosisteminin sürdürülebilir bir şekilde değerlendirilmesi için temel toprak özelliklerinin açıklanması oldukça önemlidir. Bu çalışmada Türkiye'nin subasar ormanlarının temel toprak özelliklerinin CBS ile değerlendirilmesi amaçlanmıştır. Bu bağlamda öncelikle Türkiye'deki literatürde bahsedilen 9 subasar ormanı ve sınırları belirlenmiştir. Bunlar Acarlar, Hacıosman (Meşeligöl), Hendek-Süleymaniye, İğneada, Karacabey, Köyceğiz, Sarıkum, Sinop-Aksaz ve Yörükler (Galeriç) subasar ormanlarıdır. Bu subasar ormanların sınırları dahilinde temel toprak özellikleri CBS teknikleri kullanılarak açıklanmıştır. Temel toprak özellikleri, Tarımsal Araştırmalar ve Politikalar Genel Müdürlüğü tarafından paylaşıma açılan Ülkesel Toprak Bilgi Sistemi verilerinden çekilmiştir. Çalışma sonuçlarına göre akarsu sistemleri ile bağlantılı olan subasar ormanlarda genel olarak alüvyal toprakların en geniş sahada yayılış gösterdiği anlaşılmıştır. Arazi kullanımı açısından değerlendirildiğinde subasar ormanları oluşturan en geniş sınıf orman alanlarıdır. Arazi kabiliyet sınıfı bakımından değerlendirildiğinde ise II, III ve VII. Sınıf araziler subasar ormanları genel olarak karakterize eden alanlardır.

Anahtar kelimeler: Subasar orman, CBS, toprak, arazi kullanımı, arazi kabiliyet sınıfı

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1. Introduction

Oceans, lakes, rivers, ponds and other water bodies, which constitute or influence the formation of natural resources worldwide, form different ecosystems in the geography in which they are located. Ecosystems where the ground is wet or saturated with water and where water-loving plants dominate are called wetlands. Wetlands are home to more plant species than their surroundings, as well as being a habitat for endemic species and various creatures. These characteristics make wetlands an inclusive upper class (Çiçek, 2004; Ramsar, 2005; Wetlands Convention Communication Database, 2024). According to Ramsar, the Convention on Wetlands, a wetland is any natural or artificial reedbed, wet meadow, swamp, peat bog, lake or marine area, saturated and mobile, fresh, alkaline or saline, with a water depth of less than 6 meters. These subclasses with different characteristics form different types of ecosystems within themselves and are home to many species (Hasançavuşoğlu, 2018; Yeler et al. 2023; Solak & Yılmaz, 2021). These are wetlands that are the habitat of primitive plants such as liverwort (Sarıoğlu & Keçeli, 2018). However, they are ecologically important structures in producing oxygen, absorbing nutrients, creating microclimates, filtering pollution, influencing global climate change and in the groundwater recharge/discharge cycle (Bani & Elmas 2022). Therefore, it is necessary to protect important wetlands (Toker & Sunar 2018).

Turkey has different types of wetlands of which some have been protected under different status, but all the components of floodplain forests have not been sufficiently studied (Çiçek, 2004). Although scientific studies have been carried out on the existence of forests, vegetation, landscape features and tourism potential, studies on the soil, which is one of the most basic elements of the ecosystem, have been insufficient. Since floodplain forests have a higher plant diversity compared to other forests, soil properties are very important both to explain this diversity and to ensure its sustainability (Gallardo, 2003; Parolin et al., 2004; Heger et al., 2021). In this study we mapped the soil properties of floodplain forests in Turkey using Geographic Information Systems (GIS) from the National Soil Information System data provided by the General Directorate of Agricultural Research and Policies to assess the soil properties of floodplain forests in general (TAPGM, 2017). Floodplain forests are one of the most fragile ecosystems of the Middle Belt, which are currently 9 in Turkey. Although Efe (2004) mentions the existence of various floodplain forests, these ecosystems have disappeared after being destroyed by humans.

Floodplain forests are located downstream of large streams and rivers (Gallardo, 2003). As all floodplains are associated with one or more rivers, alluvial soils are common to all floodplains. The alluvial soils that accumulate in the downstream part have flat and almost flat slope characteristics. They have normal permeability, are well drained, have no salinity and alkalinity problems and are suitable for dryland and irrigated agriculture (Bozyiğit, 2020; Table 1). This part, which corresponds to the briquette part of the material carried by the river, is very fertile and, together with water, is the basic element of the micro-scale floodplain ecosystem. Soil, which is an element of floodplain forests worthy of research as much as aboveground resources, is important because it allows different types of tree groups to grow depending on its quality (Tuncer & Kaya, 2010). Due to their ecological, biological, environmental and economic importance, floodplain forests play multiple functional roles in the natural landscape (Bozkaya et al., 2014). Floodplain forests, which are similar to the mangrove forests of the tropical belt but with certain differences, are very important forest resources in the Middle Belt. Turkey has part of the largest floodplain forest ecosystem in the middle belt. Changes in the regime of the rivers that feed the floodplain forests are a constant problem for the floodplain forests. At the same time, the fact that these forests are established on the bottom lands and their soils are fertile, leaves the ecosystem with another problem such as land use demand (Yeni, 2004).

2. Material and Method

The list of flooded forests included in the study was obtained through a literature review (Çiçek, 2004). The locations and boundaries of the flooded forests that have survived to date were compiled from scientific studies (Bahadır and Özlü, 2014; Sürmen, 2018; Hasançavuşoğlu, 2018; Karaduman, 2019; Özdemir, 2019; Akyiğit, 2020; Ürker, 2020; Ürker and Yorulmaz, 2020; Bani and Elmas, 2022). The boundary data of the obtained floodplain forests were digitized in ArcGIS PRO 3.0. The soil data and land use land cover data of the floodplain forests were obtained from the General Directorate of Agricultural Research and Policies (TAPGM, 2017). The floodplain forests examined were

İğneada, Acarlar, Hendek-Süleymaniye, Sarıkum, Sinop-Aksaz, Yörükler, Hacıosman, Karacabey, Köyceğiz floodplains.

3. Results and Discussion

Among the flooded forests, the flooded forests of Acarlar, Hacıosman (Meşeligöl), İğneada, Sarıkum, Sinop-Aksaz and Yörükler (Galeriç) are located on the Black Sea coast, while the remaining three are located on the Marmara coast. Karacabey on the coast of Marmara Sea, Hendek-Süleymaniye is located within the provincial border of Sakarya and is not on the sea coast, and finally Köyceğiz floodplains are located in the Aegean region and have shown tolerance to climate change. Despite its tolerance to climate change and summer drought, the Köyceğiz floodplain has been severely affected by anthropogenic destruction. As the remaining small patches of forest are not visible on the map, they have been transferred to the map within an inclusive area. The numbered maps are 1. İğneada, 2. Acarlar, 3. Hendek-Süleymaniye, 4. Sarıkum, 5. Sinop-Aksaz, 6. Yörükler, 7. Hacıosman, 8. Karacabey, 9. Köyceğiz floodplains (Figure 1). The soils of the floodplain forests in Turkey are divided into major soil groups, which are upper categories, according to their pedogenetic characteristics. The distribution of the soil groups identified by letters in Table 1 is shown in Figure 2. Red-brown Mediterranean soils, which are found only around the Köyceğiz floodplain, are present in areas where the continental semi-arid climate prevails (Atalay, 2016). Hydromorphic alluvial soils, which have excessive soil moisture in the degree of wetness, have a structure that prevents drainage and have high moisture retention rates because they are formed in flat, low slope and depression areas (Horasan, 2014). As slope debris, calcareous brown forest soils are present in some floodplains, red yellow podzolic soils in Sinop-Aksaz and Sarıkum floodplains, and calcareous brown forest soils in our floodplain forests.

3.1. List of flooded forests according to land use capability class

The list of flooded forests according to land capability classification is given in Table 2. In general, flat, nearly flat, deep and fertile lands with fertile soils that can be cultivated and lands with excessive slope, stony structure, swamp and other unfavorable soil characteristics, which are not suitable for cultivation, are present in all floodplain forests in Turkey (Özşahin & Eroğlu, 2018).

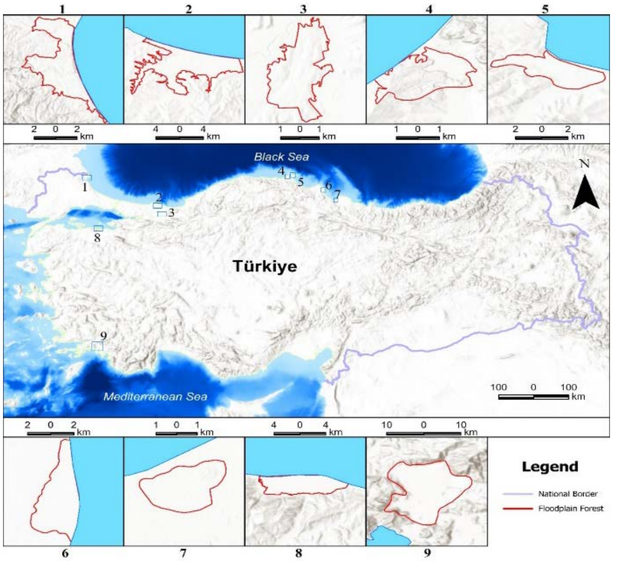

Figure 1. General combination ability of popcorn genotypes according to tester lines.

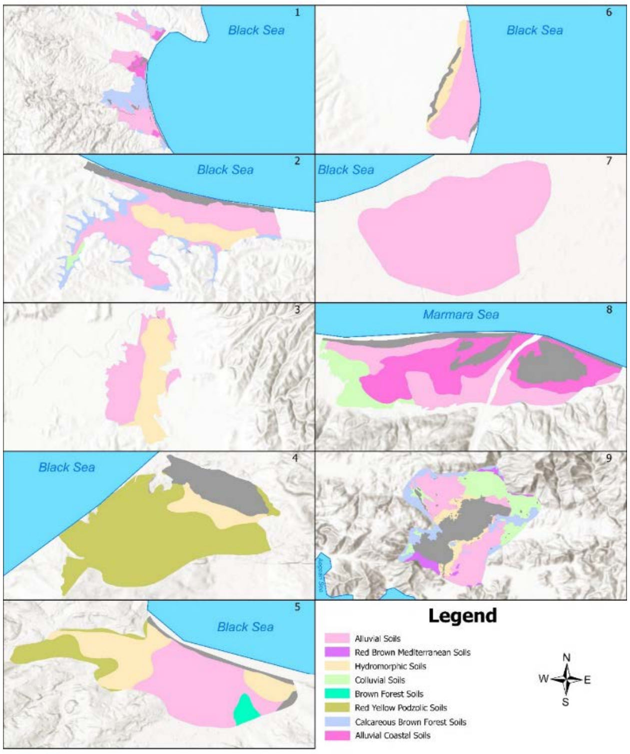

Figure 2. Map of large soil groups of the study area (TAPGM, 2017).

Table 1. List of large soil groups found in flooded forests

	Sand
A	Alluvial Soils
E	Red Brown Mediterranean Soils
H	Hydromorphic Alluvial Soils
K	Colluvial Soils
M	Brown Forest Soils
P	Red Yellow Podzolic Soils
N	Calcareous Brown Forest Soils
S	Alluvial Coastal Soils

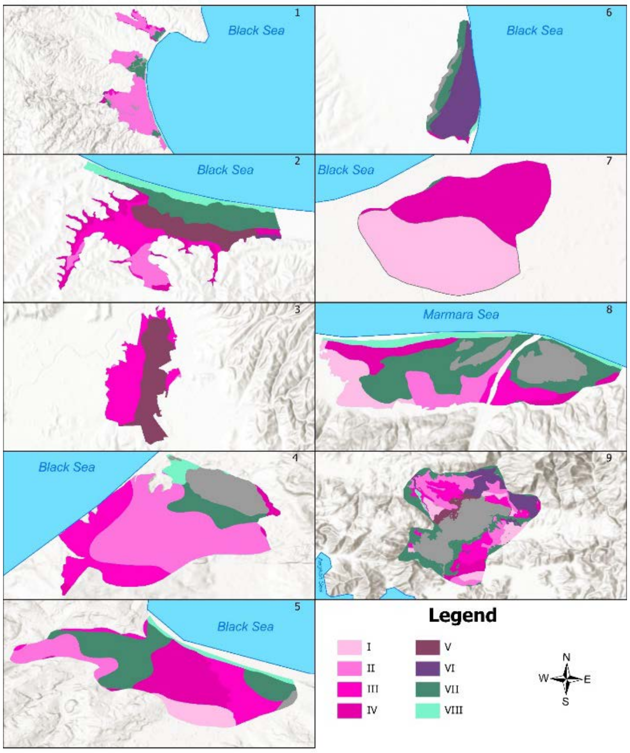

Figure 3. LULUC map of the study area (TAPGM, 2017).

Table 2. Land Capability Classification

	Land suitable for cultivation	Land not suitable for cultivation
1	II, III, IV	V, VI, VII, VIII
2	I, IV	VII
3	II, III	V, VI
4	II, III, IV	VI, VII, VIII
5	I, II, III, IV	VII, VIII
6	I, II, III, IV	V, VI, VII, VIII
7	II, III, IV	VII, VIII
8	I, II, III, IV	VII, VIII
9	IV	VI, VII, VIII

4. Conclusion

Zonal, azonal and intrazonal soil types are observed in the study areas. For the safety of the alluvial forests and their surroundings, which are rich in soil diversity, planning and agriculture should be carried out in ccordance with the identified soils. The surrounding areas of floodplain forests should be closed to settlement and soil pollution should be prevented. The water resources of these wetlands, which are very suitable for endemic plants, should be protected. Hydroelectric dams should not be built on the rivers that feed the floodplain forests, and the sustainability of these oxygen-rich forests should be ensured. Even if there are areas in the study area that can be cultivated according to the land's capacity, the most appropriate solution is to limit the use of these areas with observation, scientific studies and educational programs. As these forests are also one of the stopping points for bird migration, natural life can also be damaged by human activities.

Another advantage of flooded forests is that they store carbon. This characteristic makes floodplain forests one of the most productive areas. This is because soil organic carbon levels are high in forests with active river connections. The formation of hydromorphic features close to the mineral soil surface is a sign that soils store high levels of organic carbon. In this respect, it is important to protect the soils of alluvial forests, which will be a legacy for future generations.

On the other hand, floodplain forests that are mentioned in the literature but have lost their quality and natural resources can be studied and better protection methods can be developed for existing floodplain forests.

Conflict of interest

The authors declare no conflicts of interest.

Authorship contribution statement

H.S: Control, research design, and writing process. M.Ö: Research and writing process.

References

Atalay, İ. (2016). Toprak oluşumu, sınıflandırması ve coğrafyası, 5. Baskı.

Bahadır, M. & Özlü, T. (2014). Ağaçli Sulakalanlara Bir Örnek: Yörükler Su Basar Ormanı (Kızılırmak Deltası). *Journal of International Social Research*, 7(35).

Bani, B., & Elmas, E. (2022). Aksaz Sulak Alanı (Sinop)'nın floristik özellikleri. Biological Diversity and Conservation, 15(2), 195-217. https://doi.org/10.46309/biodicon.2022.1105095

Bozkaya, A. G., Balcık, F. B., Goksel, C., Dogru, A. O., Ulugtekın, N. N., & Sozen, S. (2014). Satellıte-based multıtemporal change detectıon ın igneada flooded forests. Romanian Journal of Geography/Revue Roumaine de Géographie, 58(2).

Bozyigit, R. (2020). Seydikemer ilçesi (Muğla) topraklarının özellikleri ve kullanımı üzerine bir değerlendirme. Avrupa Bilim ve Teknoloji Dergisi (18), 695-706. https://doi.org/10.31590/ejosat.702654

Çiçek, E. (2004). Subasar ormanların özellikleri ve Türkiye'nin subasar ormanları. *Journal of the Faculty of Forestry Istanbul University*, 54(2), 107-114.

Craft, C. (2022). Creating and restoring wetlands: from theory to practice. *Elsevier*. https://doi.org/10.1016/C2012-0-03647-2

Doğru, E., & Aydin, F. (2019). Local people's vıews on natıonal parks: the example of Igneada Longoz Forests Natıonal

Park. *International Journal of Geography and Geography Education (IGGE),* 42, 328-355.

Gallardo, A. (2003). Spatial variability of soil properties in a floodplain forest in northwest Spain. *Ecosystems*, 6, 564-576.

Hasançavuşoğlu, Z. (2018). Sarıkum Gölü'nde ötrofikasyona neden olan kirleticiler ve kaynakları (Yüksek Lisans Tezi), Temel Bilimler Ana Bilim Dalı, Fen Bilimleri Enstitüsü, Sinop, 2018

Heger, A., Becker, J. N., Vásconez Navas, L. K., & Eschenbach, A. (2021). Factors controlling soil organic carbon stocks in hardwood floodplain forests of the lower middle Elbe River. *Geoderma*, 404, 115389. https://doi.org/10.1016/j.geoderma.2021.115389

Horasan, B. Y. (2015). Konya çevresindeki toprakların jeokimyası (Doktora Tezi). Jeoloji Mühendisliği Anabilim Dalını, Fen Bilimleri Enstitüsü, Konya.

Özşahin, E. & Eroğlu, İ. (2018). Ekolojik koşullara göre Tekirdağ ilinin arazi kabiliyet sınıflandırması. Kriter Yayınları.

Parolin, P., Simone, O. D., Haase, K., Waldhoff, D., Rottenberger, S., Kuhn, U., Kesselmeier, J., Kleiss, B., Schmidt, W., Piedade, M. T. F., & Junk, W. J. (2004). Central Amazonian Floodplain Forests: Tree Adaptations in a Pulsing System. Botanical Review, 70(3), 357-380.

Ramsar Web Sayfası, (2005). https://www.ramsar.org/2005-awards

Sarıoğlu, S., & Keçeli, T. (2018). Contributions to the Liverwort (Marchantiophyta) Flora of Acarlar Lake Floodplain Forest (Sakarya). *Anatolian Bryology*, 4(2), 107-121. https://doi.org/10.26672/anatolianbryology.460427

Sulak Alanlar Sözleşmesi İletişim Veritabanı, (2024). https://contacts.ramsar.org/notification/view/2736

Sürmen, B. (2018). Su basar orman ekosistemlerinde tahribat derecelerinin türlerin strateji ve ekolojik gösterge değerlerine göre belirlenmesi (Doctoral Thesis). Fen Bilimleri Enstitüsü, Biyoloji Ana Bilim Dalı, Ondokuz Mayıs Üniversitesi, Samsun. https://acikbilim.yok.gov.tr/handle/20.500.12812/674584

Tarımsal Araştırmalar ve Politikalar Genel Müdürlüğü, (2017). Topraksu. Kırklareli ili envanter haritası. Ankara: Köy İşleri Bakanlığı, Toprak su Genel Müdürlüğü, Toprak Etüdleri ve Harita Dairesi Başkanlığı, Arazi Sınıflandırma Şubesi. 1972. Bakanlık Yayınları. 165. Genel Müdürlük Yayınları. 249. Raporlar Serisi: 37; 1972.

Toker, M., & Sunar, F. (2018). Korunan alanların zamansal değişiminin landsat uydu görüntüleri ile analizi: İğneada Longoz Ormanları örneği. VII. Uzaktan Algılama-CBS Sempozyumu (UZAL-CBS 2018), 18-21 Eylül 2018, Eskişehir

Tuncer, M.M., & Kaya, N.Ö. (2010). Orman ve su kaynakları orman ve su ekosistem ilişkisi. III. Ulusal Karadeniz Ormancılık Kongresi. 20-22 Mayıs 2010. Cilt: II Sayfa: 625-640.

Ürker, O. (2020). Hacıosman Ormanı Tabiatı Koruma Alanı (Samsun) Florası, Vejetasyon ve Habitat Yapısı ile Genel Bitki Ekolojisi Özellikleri Üzerine Bir Değerlendirme. *Bitlis Eren Üniversitesi Fen Bilimleri Dergisi*, 9(1), 168-193. https://doi.org/10.17798/bitlisfen.679543

Urker, O., & Yorulmaz, T. (2020). Köyceğiz-Dalyan Özel Çevre Koruma Bölgesi'ndeki Anadolu sığla ormanlarında yarasa (Chiroptera) aktivitesinin belirlenmesi. *Ormancılık Araştırma Dergisi*, 7(1), 88-103. https://doi.org/10.17568/ogmoad.651223

Yeler, O., Çamur Elipek, B., & Aydın, G. B. (2023). Mert Gölü (İğneada Longoz Ormanları Milli Parkı / Kırklareli) Morfolojisinde Zamansal Değişimin CBS Desteğiyle İncelenmesi ve Ekolojik Açıdan Değerlendirilmesi. *Türk Tarım Ve Doğa Bilimleri Dergisi*, 10(4), 876-886. https://doi.org/10.30910/turkjans.1298920

Yeni, E. (2005). Subasar (longoz) orman ekosistemlerinin karakteristikleri ve bu ekosistemlerin korunmasinda karilaşilan sorunlarin çözüm ilkeleri. www.academia.edu/97351855

Yilmaz, O. & Solak, R.D. (2021). Biyosfer rezerv olanaklarının irdelenmesinde örnek bir çalışma: Acarlar Longozu. Journal on Mathematic, *Engineering and Natural Sciences*, 5(20), 900-910.

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Effects of modified atmosphere packaging and putrescine application on postharvest storage and shelf life of 'Rosy Glow' apple cultivar⁎

Sarahnur KARADAŞLI[1], Emine KÜÇÜKER[2]*, Erdal AĞLAR[1], Selda DEMiR[1]

[1]Siirt University, Faculty of Agriculture, Department of Horticulture, Siirt, Türkiye
[2]Van Yuzuncu Yil University, Faculty of Agriculture, Department of Horticulture, Van, Türkiye

***Corresponding author e-mail:** emine.kucuker@siirt.edu.tr

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Abstract: The current study evaluated the effects of modified atmosphere packaging (MAP) and Putrescine applications on fruit quality during postharvest storage and shelf life of 'Rosy Glow' apple cultivar. Quality parameters, i.e., weight loss, decay rate, total soluble solids content (SSC), titratable acidity (TA), fruit flesh firmness and color changes were investigated during different storage periods. Low levels of weight loss were observed in all applications during the 30th day while losses increased in control treatment after the 60th day (3.58%) and the lowest loss rate (1.27%) was recorded in the MAP + Putrescine application. The MAP + Putrescine group showed the lowest loss rate (2.28%) on the 120th day making it the most effective preservation technique. The decay rate increased during the storage period while MAP and Putrescine applications prevented decay and MAP+Putrescine combination kept the decay rate at the lowest level. The MAP+Putrescine application completely prevented the decay rate on the 120th day. The SSC ratio decreased during the storage period, MAP and Putrescine applications maintained the fruit carbohydrate content better whereas Putrescine application showed the highest SSC value. The TA values generally decreased during the storage, but MAP and Putrescine applications minimized TA loss. The MAP and Putrescine applications better maintained TA during shelf life. The MAP and Putrescine applications better maintained fruit flesh firmness, MAP application provided the highest firmness value on the 120th day. Firmness loss was more pronounced 'n the control group. In all applications, the changes were observed in L*, a*, b* and hue values over time. L* value remained lower in control on the 120th day, but MAP and MAP+Putrescine applications maintained the brightness level of the fruit peel. MAP treatment initially affected the hue angle more. As a result, MAP and Putrescine applications effectively maintained fruit quality in 'Rosy Glow' apple cultivar during storage while MAP+Putrescine combination stood out as the most effective preservation technique.

Keywords: Decay rate, fruit flesh firmness, titratable acidity, total soluble solids, weight loss.

Modifiye atmosfer paketleme ve putresin uygulamalarının 'Rosy Glow' elma çeşidinin hasat sonrası depolama ve raf ömrü üzerine etkileri

Öz: 'Rosy Glow' elma çeşidinde hasat sonrası depolama ve raf ömrü süresince Modifiye Atmosfer Paketleme (MAP) ve Putresin uygulamalarının meyve kalitesi üzerine etkileri değerlendirilmiş ve farklı depolama dönemlerinde ağırlık kaybı, çürüme oranı, toplam çözünür kuru madde içeriği (SSC), titre edilebilir asitlik (TA), meyve eti sertliği ve renk değişimleri gibi kalite parametreleri incelenmiştir. Tüm uygulamalarda 30 gün boyunca düşük seviyelerde ağırlık kaybı gözlenirken, 60. günden sonra kontrol grubunda kayıplar artmış (%3,58) ve en düşük kayıp oranı (%1,27) MAP+Putresin uygulamasında kaydedilmiştir. 120. günde, MAP+Putresin grubu en düşük kayıp oranını (%2,28) göstererek en etkili muhafaza tekniği olmuştur. Depolama süresince çürüme oranı artarken, MAP ve Putresin uygulamaları çürümeyi önlemiş ve MAP+Putresin kombinasyonu çürüme oranını en düşük seviyede tutmuştur. 120. günde MAP+Putresin uygulaması çürüme oranını tamamen engellemiştir. SSC oranı depolama süresince azalmış, MAP ve Putresin uygulamaları meyve karbonhidrat içeriğini daha iyi korumuş ve özellikle Putresin uygulaması en yüksek SSC değerini vermiştir. TA değerleri depolama süresince genel olarak azalmış, ancak MAP ve Putresin uygulamaları TA kaybını en aza indirmiştir. Raf ömrü boyunca MAP ve Putresin uygulamaları TA değerini daha iyi korumuştur. MAP ve Putresin uygulamaları meyve eti sertliğini daha iyi korumuş,

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MAP uygulaması 120. günde en yüksek sertlik değerini sağlamıştır. Kontrol grubunda meyve eti sertliğindeki kayıp daha belirgin olmuştur. Tüm uygulamalarda L*, a*, b* ve hue açısı değerlerinde zaman içinde değişimler gözlenmiştir. L* değeri 120. günde kontrol grubunda diğer uygulamalara kıyasla daha düşük kalmıştır, ancak MAP ve MAP+Putresin uygulamaları meyve kabuğunun parlaklık seviyesini daha iyi korumuştur. MAP uygulaması başlangıçta hue açısını daha fazla etkilemiş, ancak zamanla diğer uygulamalarla benzer sonuçlar elde edilmiştir. Sonuç olarak, MAP ve Putresin uygulamaları 'Rosy Glow' elma çeşidinde depolama sırasında meyve kalitesini etkili bir şekilde korurken, MAP+Putresin kombinasyonu en etkili muhafaza tekniği olarak öne çıkmıştır.

Anahtar kelimeler: Ağırlık kaybı, çürüme oranı, meyve eti sertliği, titre edilebilir asitlik, toplam çözünebilir kuru madde.

1. Introduction

Apple (*Malus domestica* Borkh.) is a fruit species widely produced in the world by adapting to different climatic conditions. Türkiye has an important share in global apple production (Coskun & Askın, 2016; Gunay et al., 2021). The apple production has increased in Türkiye over the years. Similarly, preservation of fruit quality has gained great importance ove these years in the country. Sensitive fruits such as apples can suffer from various deteriorations and quality losses during post-harvest processes. Hence, preventing these losses directly contributes to the trade of the product (El Ghaouth et al., 2004; Sharma et al., 2009; Wani et al., 2022). The quality losses of apples are generally associated with high respiration rate, ethylene production, water loss and spoilage due to microorganisms. In this context, effective preservation methods must be applied to preserve fruit quality.

The use of biological compounds such as MAP and putrescine has become remarkably widespread in recent years for fruit preservation. These compounds slow down the respiration rates of fruits by controlling their environmental conditions and changing the oxygen and carbon dioxide levels of the fruits. These methods have been successful in improving fruit quality and extending shelf life. The MAP protects fruit health and prevents quality losses. Moreover, MAP application exhibits effective results in fruits such as apples. This technology slows down fruit respiration, reduces ethylene production and controls fruit ripening (Ben Yehoshua, 1999; Sisler & Serek, 2003; Kader & Rolle, 2004; Rojas Grau & Martin-Belloso, 2007; Chien & Chien, 2013). Studies have shown that MAP significantly reduces quality losses by extending the shelf life of fruits. For example, Turk and Karaca (2015) reported that MAP applications ensured that apple fruits remained fresh for a longer time by maintaining their color and firmness. In addition, reducing ethylene level with MAP slows down fruit ripening (Ustunel et al., 2008; Kaushal et al., 2020).

Putrescine is an organic compound and a polyamine that plays a significant role in cellular growth, differentiation and aging processes (Erbas et al., 2018). Various studies show that putrescine application increased fruit quality and prevented physiological deterioration during storage. For example, Malik and Singh (2003) reported that putrescine application delay ripening by reducing ethylene production in apple fruits. In addition, Dibble et al. (1988) emphasized that putrescine applications prevented quality losses by slowing down the fruit respiration rate. The 'Rosy Glow' apple attracts attention with its bright pink skin and sweet, crisp texture, and can retain its value for longer time with the right preservation techniques. In this study, the effects of post-harvest applied putrescine (1 mM) and MAP technologies on fruit quality during post-harvest storage and shelf life in 'Rosy Glow' apple cultivar were investigated.

2. Materials and Methods

2.1. Plant material

The plant materials used in the study included ''Rosy Glow'' apple cultivar grafted onto the 'MM106' rootstock planted in a producer's orchard in Yunuslar town of Kurtalan district of Siirt province. The orchard is located at an altitude of 595 m and between the 370 55' 27' N parallel and 410 21' 17' E meridians. The trees were planted at 4×4 m distance, and a wire training system was established according to the central leader training system. Irrigation is carried out with a drip irrigation system, and other cultural practices such as pruning, fertilizing, and spraying are carried out regularly in the orchard.

2.2. Methods

Fruits harvested at commercial maturity were quickly transported to the Siirt University laboratory. Damaged fruits during transportation were sorted and excluded from the evaluation. Fruits selected according to color and size criteria were divided into 4 different groups and treatment applications were initiated. The fruits in the first group were regarded as control, immersed only in pure water and left to dry at room temperature. The dried fruits were placed in plastic bowls and stored in cold storage after weighing. The fruits in the second group were subjected to a pre-cooling process at 1°C for 24 hours to reduce the fruit temperature to 3–4°C. After cooling, the fruits were placed in 5 kg capacity Xtend® MAP packages closed with plastic clips. The packaged fruits were quickly transported to the cold storage. The fruits in the third group were immersed in 1 mM putrescine solution for 10 minutes and then dried on blotting paper for 20 minutes. The fruits in the fourth group were immersed in 1 mM putrescine solution for 10 minutes, dried on blotting paper for 20 minutes, and stored in MAP packages. Control and treated fruits were stored in cold storage at 1°C and 90±5% humidity for ~120 days. Measurements and analyses of fruit quality traits were carried out in Siirt University and Iğdır University laboratories. Apple samples were subjected to physical and chemical analyses at the beginning of storage and on 30th, 60th, 90th and 120th days. Each application was arranged in 3 replications and 30 fruits were used in replication. A total of 5 fruits were taken from each replication in each tretatment to determine the shelf life of fruits during each analysis period and kept at 20±1°C for 5 days. Measurements and analyses were made at the end of 5 days.

2.3. Weight loss (%)

Initial weights (Wi) of the fruit were determined by a digital scale with a precision of 0.01 g (Radwag, Poland) at the beginning of the cold storage. Afterwards, final weights (Wf) were determined on 30th, 60th, 90th and 120th days of the storage. The weight loss was based on the weight at the beginning of each measurement period and determined as a percentage (%) through the equation given below (Eq.1).

$$WL = \frac{Wi - Wf}{Wi} \times 100 \quad (1)$$

2.4. Decay rate (%)

Ten (10) fruits were used in each replication and the total number of fruit (TF) was determined before cold storage. The decayed fruits (DF) in each replication were determined during each observation period. The fruits were considered rotten if the development of mycelium was recorded on shell. The Eq .2 was used to compute the decay rate (DR, %).

$$DR = \frac{TF - DF}{TF} \times 100 \quad (2)$$

2.5. Soluble solids content and titratable acidity (%)

The amount of water-soluble solids (SSC) was determined as % by refractometer and the amount of acidity was determined as malic acid by titration method as % in 10 ml of juice extracted from hawthorn fruit.

2.6. Fruit flesh firmness

The fruit firmness was measured by touching the opposite cheeks of the equatorial part of five fruits with a digital penetrometer (Agrosta 100 field, Agrotechnologie, France) with the 10-point tip of the device perpendicularly (Blankenship at al., 1997).

2.7. Fruit color

L*, a*, b* and hue angle values in fruit peels were determined using a Minolta, CR-400 color measurement device. The color measurement device was calibrated with a white standard plate (Y = 92.40 x = 0.3137 y = 0.3195). Fruit peel and flesh color were determined in 6 fruits from each treatment. Flesh color was measured bidirectionally from the center of the fruit, and flesh color was measured from two lateral parts of the longitudinal section (Sacks & Shaw, 1994; Gunduz & Ozdemir, 2003).

2.8. Statistical analyses

The randomized plot experimental design was established with three replications and 30 fruits in each replication to determine the change that occurred at each observation period. Data were analyzed with variance analysis, the significance level of the differences between the application means was determined with Duncan multiple research test.

3. Results and Discussion

3.1. Weight loss (%)

The weight loss rates were low in all applications during the first 30 days with non-significant differences among treatments. However, the differences between treatments increased after the 60th day. The highest weight loss was recorded for control (3.58%), whereas MAP+Putrescine resulted in the lowest (0.69%) weight loss. Likewsie, MAP+Putrescine resulted in the the lowest weight loss (1.27%) on the 90th day, while the loss in control was 3.27%. On the 120th day, MAP+Putrescine treatment resulted in the lowest loss (2.28%), while the loss in control increased to 3.56%.

During shelf life, the differences between the treatments were significant for different storage periods. On the 30+5th day, the highest loss was observed in control (11.15%), while lower losses were observed in the MAP application (8.75%) and the Putrescine application (5.99%). The lowest loss was observed in the MAP+Putrescine application (4.69%). On the 60+5th day, 17.60% loss was observed in control, similar losses were observed in the MAP and Putrescine applications while the lowest loss (3.26%) was recorded in the MAP+Putrescine application. On the 90+5th day, MAP (7.55%) and MAP+Putrescine (4.27%) applications provided lower losses than the control group. MAP+Putrescine application gave the lowest loss with 2.39% on the 120+5th day whereas the loss in control was the highest with 17.14% (Table 1).

Table 1. The effect of putrescine and MAP applications on weight loss of 'Rosy Glow' apple cultivar.

Weight loss (%)				
Applications	Storage time (day)			
	30	60	90	120
Control	0.99a	3.58a	3.27a	3.56a
MAP	0.65a	1.70c	1.99b	2.29b
Putrescine	0.81a	2.03b	2.15ba	2.67b
MAP+Putrescine	0.57a	0.69d	1.27b	2.28b
	Shelf life (day)			
Applications	30+5	60+5	90+5	120+5
Control	11.15a	17.60a	17.36a	17.14a
MAP	8.75ba	7.84b	7.55b	7.34c
Putrescine	5.99b	8.01b	2.79b	12.61b
MAP+Putrescine	4.69b	3.26b	4.27b	2.39d

* Means in columns with the same lower case do not differ according to Duncan' s test at P<0.05.

Weight loss occurs because of evaporation of water in the fruit through transpiration and increases in proportion to the storage period (Kader & Yahia, 2011; Candir et al., 2018; Kucuker et al., 2024). These losses cause significant economic problems for fruit producers (Sandhya, 2010). It is stated that weight loss occurs due to metabolic activities such as transpiration and respiration (Lownds et al., 1993). Applications of polyamines, especially MAP and putrescine, prevent weight loss by slowing down fruit respiration and delaying the degradation of cell walls (Champa et al., 2014; Fawole et al., 2020). MAP, Putrescine and MAP+Putrescine provided lower respiration rate and parallelly less weight loss. Archana and Suresh (2019) reported that putrescine and spermidine applications were effective in reducing weight loss. In addition, Avci (2016) and Ogurlu et al. (2024a) indicated that MAP application reduces weight loss by decreasing respiration rate. These findings show that MAP and putrescine are effective in preserving fruit quality, playing an important role in fruit preservation.

3.2. Decay rate (%)

Decay occurs in fruits during the post-harvest storage period, depending on the species and cultivar (Zafari et al., 2015). The decay rates increased as the storage period progressed. The decay rate of 1.33% in control group on the 30th day increased to 2.86% on the 120th day. MAP application resulted in a low decay rate (0.71%) on 30th day, which increased to 1.71% on the 120th day. Putrescine application showed a low decay rate (0.46%) on the 30th day, which increased to 1.52% on the 120th day. Similarly, MAP+Putrescine resulted in 1.55% decay rate on the 120th day. Observations during shelf life showed that no decay occurred in all applications on 30+5th day, while on the 60+5th day, 0.77% decay was observed in the control group, and no decay occurred in the other groups. On the 90+5th day, the decay rate increased to 1.71% in control, while 0.10% decay was observed in MAP+Putrescine application and 0.58% in MAP. On the 120+5th day, 1.77% decay rate was observed in control, 1.16% in MAP application, and no decay was observed in Putrescine and MAP+Putrescine applications. These results show that Putrescine and MAP+Putrescine applications completely prevented decay, while MAP application controlled decay (Table 2).

Polyamines such as putrescine and spermidine, which have anti-pathogenic properties, play a significant role in plant defense mechanisms (Hanif et al., 2020; Kucuker et al., 2023a). Champa et al. (2014) reported that polyamines are conjugated to phenolic compounds and hydroxycinnamic acid amides and that there is a good correlation between the accumulation of hydroxycinnamic acid amides and pathogen resistance. In our study, the decay rate in fruits increased in parallel with the storage period but was lower in treated fruits. Indeed, MAP have been reported to reduce the respiration rate by changing the gas atmosphere in the environment, thus slowing down the decay rate (Ogurlu et al., 2024b). Polyamine applications reduced rotting and cold-induced damage in peach (Zokaee Khosroshahi et al., 2008; Kibar et al., 2021), pomegranate (Barman et al., 2011), apricot (Martinez-Romero, 2006), papaya (Hanif et al., 2020), strawberry (Khosroshahi et al., 2007), mandarin (Ennab et al., 2020) and mango (Jawandha et al., 2012) fruits, and maintained fruit quality during cold storage.

3.3. Soluble solids content and titratable acidity

The amount of SSC and TA have a significant effect on the storage period of the fruit. The amount of SSC increases while the titratable acidity decreases as the ripening progresses in the fruit, (Mahto & Das, 2013; Abd El-Gawad et al., 2019; Kucuker et al., 2023b).

The SSC content was at similar levels during harvest in all applications in the current study (i.e., control = 16.2%, MAP = 15.61%, Putrescine = 14.96% and MAP+Putrescine = 16.41%). No significant difference was observed between the treatmentns on 30th and 60th days of storage. On the 90th day, the highest SSC was observed in control (18.96%) while lower values were observed in the Putrescine and MAP applications. Similarly, the lowest SSC value was found in control (14.40%) on 120th day, while MAP (16.41%) and MAP+Putrescine (16.40%) applications showed higher values. These results show that MAP and Putrescine better maintained carbohydrate content of the fruits. Observations made during the shelf life also yielded similar results. On the 30+5th day, higher SSC values were recorded with MAP and Putrescine, while a significant decrease was observed in these applications on the 60+5th day. On the 90+5th day, SSC values were close to each other in MAP and Putrescine applications, but this value decreased significantly in control. On the 120+5th day, the highest SSC value (10.65%) was obtained with Putrescine application. The lowest value was recorded in the control group with 7.80%. This reveals that Putrescine application best preserves the carbohydrate content of the fruits (Table 3).

Table 2. The effect of putrescine and MAP applications on decay rate of 'Rosy Glow' apple cultivar.

Decay rate (%)				
Applications	Storage time (day)			
	30	60	90	120
Control	1.33a	2.55a	2.77a	2.86a
MAP	0.71a	1.21b	1.26b	1.71b
Putrescine	0.46a	0.55b	1.11b	1.52b
MAP+Putrescine	0.58a	1.07b	1.28b	1.55b
	Shelf life (day)			
Applications	30+5	60+5	90+5	120+5
Control	0.00a	0.77a	1.71a	1.77a
MAP	0.00a	0.00b	0.58b	1.16b
Putrescine	0.00a	0.00b	0.00c	0.00c
MAP+Putrescine	0.00a	0.00b	0.10c	0.12c

* Means in columns with the same lower case do not differ according to Duncan' s test at P<0.05.

Table 3. The effect of putrescine and MAP applications on total soluble solids of 'Rosy Glow' apple cultivar.

Soluble solids content (%)					
Applications	Storage time (day)				
	Harvest	30	60	90	120
Control	16.2	16.38a	16.96a	18.96a	14.40b
MAP		15.61a	16.45a	17.34b	16.41a
Putrescine		14.96a	15.67a	15.77c	16.37a
MAP+Putrescine		16.41a	15.73a	15.80c	1640a
	Shelf life (day)				
Applications		30+5	60+5	90+5	120+5
Control	16.2	10.33a	14.36b	8.50b	7.80b
MAP		17.57a	17.99a	10.76a	10.37a
Putrescine		15.60a	18.93a	10.57a	10.65a
MAP+Putrescine		14.73a	16.93ba	10.87a	10.60a

* Means in columns with the same lower case do not differ according to Duncan' s test at P<0.05.

The TA content was at different levels in all applications at the time of harvest (i.e., control = 1.45%, MAP = 0.85%, Putrescine = 0.83%, and MAP+Putrescine = 0.86%). On the 30th day, a decrease in TA values was observed in all applications but decreased faster (0.77%) in the control group. A similar trend continued on 60th day, with control showing the lowest value at 0.70%, while the other applications had higher TA contents. On the 90th day, the highest TA value of 0.80% was recorded in MAP, while control showed the lowest value of 0.66%. On the 120th day, MAP and MAP+Putrescine applications had the highest TA values, while the lowest TA value (0.64%) was recorded for control group. A similar trend was observed throughout the shelf life. On the 30+5th day, TA values were 0.92%, 0.86% and 0.84% in MAP, Putrescine and MAP+Putrescine applications, respectively while the lowest value was recorded in control at 0.66%. On the 60+5th day, higher TA values were observed in MAP (0.80%) and Putrescine (0.65%) applications. On the 90+5th day, TA values remained higher with small differences between MAP and Putrescine applications. On the 120+5th day, MAP and Putrescine applications had the highest TA values, but control showed the lowest value (0.38%). This reveals that MAP and Putrescine applications preserved TA better (Table 4).

Table 4. The effect of putrescine and MAP applications on titratable acidity of 'Rosy Glow' apple cultivar.

Titratable acidity (%)					
Applications	Storage time (day)				
	Harvest	30	60	90	120
Control	1.45	0.77b	0.70b	0.66c	0.64b
MAP		0.85a	0.84a	0.80a	0.78a
Putrescine		0.83a	0.82a	0.72b	0.74a
MAP+Putrescine		0.86a	0.85a	0.73b	0.75a
	Shelf life (day)				
Applications		30+5	60+5	90+5	120+5
Control	1.45	0.66b	0.65b	0.49b	0.38c
MAP		0.93a	0.92a	0.80a	0.75a
Putrescine		0.87a	0.86a	0.65a	0.70a
MAP+Putrescine		0.88a	0.84a	0.76a	0.65b

* Means in columns with the same lower case do not differ according to Duncan' s test at P<0.05.

Indeed, it has been reported that different polyamine applications delay ripening and therefore slow down postharvest SSC and TA changes (Serrano et al., 2003; Jongsri et al., 2017). Our findings are consistent with findings indicating that post-harvest putrescine applications slow down the changes in sap and stone content in plum (Serrano et al., 2003), peach (Abbasi et al., 2019; Kaur & Kaur, 2019; Kibar et al., 2021) and papaya (Hanif et al., 2020) fruits. Similarly, Khan et al. (2013) reported that post-harvest MAP applications preserved the SSC content in plum fruits. Ozturk and Aglar (2019) suggested that MAP-applied fruits in cornelian cherry had higher TA content.

3.4. Fruit flesh firmness

Fruit flesh firmness is one of the important quality parameters in apples (Song et al., 2013). As the fruit ripens, the fruit flesh firmness decreases because of the breakdown of cell wall components such as pectin substances, hemicellulose and cellulose and the decrease in turgor pressure within the cell (Mannozzi et al., 2018; Kucuker et al., 2023a). Fruit flesh firmness has an important effect on marketing and post-harvest processes in fruits, and it decreases with the progression of ripening. It is known that softening in fruits occurs because of weight loss and cell wall breakdown by enzymes such as polygalacturonase and pectinesterase (Martinez-Ferrer et al., 2002), and the main reason for weight loss and fruit flesh softening is transpiration due to the water pressure gradient between the fruit tissues and the surrounding atmosphere (Ozturk, 2012). Similar fruit flesh firmness was observed with all applications at harvest in the current study (i.e., control = 8.63%, MAP = 8.56%, Putrescine = 8.41%, and MAP+Putrescine = 8.60%). Softening was observed in fruits with all applications on the 30th day, but the highest firmness (8.60 kg) was determined in the MAP+Putrescine applications. On the 60th day, fruit firmness decreased in all applications and the lowest value (8.10 kg) was recorded with control. On the 90th day, 7.75 kg fruit flesh firmness values were measured in MAP application, 8.11 kg in Putrescine application and 8.13 kg in MAP+Putrescine application. It was determined that the firmness was lower in control fruits (7.96 kg). On the 120th day, the lowest firmness value was measured in control with 7.56 kg, while higher fruit firmness was noted in other applications. Regarding shelf life, MAP application maintained the highest hardness value (8.48 kg) on 30+5th day, while the firmness decreased more rapidly in the control group (6.91 kg). Similarly, MAP application resulted in the highest firmness value (8.34 kg) on all observation periods. This shows that MAP application maintained fruit firmness compared to the other treatments (Table 5).

MAP is an effective method for reducing weight loss and fruit softening during cold storage of various fruits and vegetables (Cantin et al., 2008; Guillen et al., 2013; Khan et al., 2013). Polyamines delay ripening by changing the stability of the cell wall in the fruit, and contribute to the protection of fruit flesh (Kucuker et al., 2023a). Putrescine application preserved fruit flesh firmness in fruit species such as plum (Serrano et al., 2003; Khan et al., 2008) and peach (Kaur et al., 2019; Kibar et al., 2021).

Table 5. The effect of putrescine and MAP applications on fruit flesh firmness of 'Rosy Glow' apple cultivar.

Fruit flesh firmness (kg)					
Applications	Storage time (day)				
	Harvest	30	60	90	120
Control	8.63	8.16b	8.10b	7.96b	7.56b
MAP		8.56a	8.37a	8.04a	7.75ab
Putrescine		8.41a	8.35a	8.20a	8.11a
MAP+Putrescine		8.60a	8.59a	8.25a	813a
	Shelf life (day)				
Applications		30+5	60+5	90+5	120+5
Control	8.63	6.91b	5.54b	4.47b	4.53b
MAP		8.56a	8.48a	8.34a	7.56a
Putrescine		8.40a	8.10a	7.65a	7.51a
MAP+Putrescine		8.57a	7.96a	7.34a	7.28a

* Means in columns with the same lower case do not differ according to Duncan' s test at P<0.05.

3.5. Fruit color

Fruit color is an observable maturity criterion in many fruit species and is an important quality trait that affects consumer preferences. The color changes occur in the fruit with post-harvest ripening and it is very important to reduce these changes. Similar L* values were observed in all applications at the time of harvest. The L* values increased in all applications on 30th day wşth the highest values recorded for MAP and Putrescine. Control and MAP+Putrescine had the highest L* values on 60th day, while the highest L* value was noted for control on 120th day. The a* value was at similar levels in all applications at harvest, and changes were observed in different applications on the 30th day. On the 120th day, MAP+Putrescine application showed low a* value. The b* value increased in all groups from day 30 days to onwards and the significant increase was observed for MAP. Although there were differences among treatments for hue, similar changes occurred in all treatments over time. Shelf life data indicated that the L* value of control was lower. MAP, Putrescine and MAP+Putrescine applications preserved the light level of the fruit peel better. In a* value, control had lower values on the 90+5th and 120+5th days while the MAP+Putrescine application showed the highest a* value. In the b* value, the Putrescine application showed the highest value on 30+5th day. In terms of hue, the MAP application initially showed higher values, but over time the differences between all applications decreased. These findings show that the MAP application affected the color tone more in the initial stages, but the other applications provided similar effects over time (Table 6). Similarly, Ozturk et al. (2021) reported that physiological and biochemical changes in MAP-applied medlar fruits were less during storage and fruit color was preserved. Cantin et al. (2008) suggested that color changes were lower with MAP application in Japanese plums. Martínez-Romero (2006) reported that putrescine reduced color changes in fruits in a study in which they treated apricot fruits harvested at commercial maturity with 1 mM putrescine and stored at 10 °C for 6 days, while Valero et al. (1998) found that lemon fruits treated with putrescine preserved their color index during storage. Gain, Martinez-Romero et al. (2002) stated that color change was lower in apricot fruits treated with putrescine.

Table 6. The effect of putrescine and MAP applications on fruit color of 'Rosy Glow' apple cultivar.

Applications		Fruit color				
			Storage Time (day)			
		Harvest	30	60	90	120
Control	L*	55.61	58.40a	59.27a	54.67a	63.08a
MAP			50.31a	61.50a	56.45a	55.65a
Putrescine			54.78a	53.24a	61.75a	59.84a
MAP+Putrescine			54.08a	61.86a	57.50a	60.94a
Control	a	18.22	22.52a	22.01a	27.44a	23.01a
MAP			26.04a	16.63a	33.29a	22.98a
Putrescine			32.38a	30.59a	19.76a	22.41a
MAP+Putrescine			26.97a	21.05a	26.87a	21.39a
Control	b	31.55	34.37a	35.00a	34.40a	36.96a
MAP			31.93a	42.05a	41.66a	43.22a
Putrescine			31.71a	33.84a	42.14a	42.90a
MAP+Putrescine			26.97a	37.83a	36.02a	40.56a
Control	hue angle	58.14	56.67a	55.77a	57.33a	56.60a
MAP			52.06a	67.77a	59.15a	61.20a
Putrescine			65.09a	48.13a	65.02a	62.11a
MAP+Putrescine			48.70a	61.00a	55.21a	63.06a
			Shelf life (day)			
Applications			30+5	60+5	90+5	120+5
Control	L*	55.61	79.34a	55.94b	46.37b	52.66b
MAP			83.61a	80.10a	80.85a	78.88a
Putrescine			82.70a	80.82a	80.93a	67.85a
MAP+Putrescine			80.14a	78.23a	80.66a	80.09a
Control	a	18.22	4.05a	3.65a	2.81b	3.59b
MAP			4.28a	3.91a	5.68a	5.65ba
Putrescine			4.20a	4.77a	4.69ba	5.37ba
MAP+Putrescine			4.33a	5.99a	6.35a	7.24a
Control	b	31.55	31.77c	37.81a	26.60a	25.73a
MAP			34.83b	39.51a	39.85a	35.53a
Putrescine			37.63a	37.92a	39.07a	42.28a
MAP+Putrescine			31.52c	27.41a	42.65a	37.32a
Control	hue angle	58.14	82.42b	81.20a	50.90a	48.79a
MAP			87.84a	85.06a	81.04a	78.13a
Putrescine			81.15b	82.94a	81.70a	69.21a
MAP+Putrescine			81.87b	84.60a	81.64a	81.40a

* Means in columns with the same lower case do not differ according to Duncan' s test at $P<0.05$.

4. Conclusion

Different treatments applied to 'Rosy Glow' apples had significant effects on weight loss rates. MAP+Putrescine combination provided the lowest weight loss and preserved apple quality for a longer period. This combination gave particularly superior results after the 60th day and lower losses. MAP+Putrescine application is an effective solution for preserving apple quality during storage. Shelf life data indicated that the same combination prevent decay and maintained the fruit quality, providing the lowest losses compared to other applications. The preservation of fruit quality was not limited to weight loss only, but also had visible effects on decay rates, soluble solids content, titretable acidity, flesh firmness and color changes. MAP and Putrescine applications preserved fruit firmness and kept acidity in the fruit under control. The MAP+Putresin combination resulted in the lowest decay rates and highest firmness values. In addition, these applications minimized fruit color changes and preserved their aesthetic quality for a longer time. As a result, MAP and Putrescine applications stand out as methods that effectively preserve fruit quality. Especially the MAP+Putrescine combination provides the most efficient results in apple storage.

Conflict of interest

The authors declare no conflicts of interest.

Authorship contribution statement

S.K: Investigation, writing – original draft, writing – review and editing. E.K: Formal analysis, data curation, investigation, writing – original draft. E.A: Formal analysis, visualization, writing –original draft. S.D: Writing – original draft.

References

Abbasi, N. A., Ali, I., Hafiz, I. A., Alenazi, M. M., & Shafiq, M. (2019). Effects of Putrescine Application on Peach Fruit during Storage. *Sustainability*, *11*(7), 2013. https://doi.org/10.3390/su11072013

Abd El-Gawad, M. G., Zaki, Z. A., & Ekbal, Z. A. (2019). Effect of some postharvest treatments on quality of 'Alphonse' mango fruits during cold storage. *Middle East Journal of Agriculture Research*, 8(4), 1067–1079. https://doi.org/10.36632/mejar/2019.8.4.9

Archana, T. J., & Suresh, G. J. (2019). Putrescine and spermine affects the postharvest storage potential of banana cv. Grand Naine. *International Journal of Current Microbiology and Applied Sciences*, 8 (1), 3127–3137.

Avcı, V. (2016). Japon Grubu (*Prunus salicina* L.) *Black Amber Erik Çeşidinin Muhafaza Performansının Belirlenmesi* [Yüksek Lisans Tezi, Ordu Üniversitesi Fen Bilimleri Enstitüsü]. Ordu Üniversitesi. http://earsiv.odu.edu.tr:8080/xmlui/handle/11489/918

Barman, K., Asrey, R., & Pal, R. K. (2011). Putrescine and carnauba wax pretreatments alleviate chilling injury, enhance shelf life and preserve pomegranate fruit quality during cold storage. *Scientia Horticulturae,* 130, 795-800. https://doi.org/10.1016/j.scienta.2011.09.005

Ben-Yehoshua, S. (1999). Effect of modified atmosphere and controlled atmosphere on postharvest physiology and quality of fresh fruits. *Postharvest Biology and Technology*, 15(3), 221-228. https://doi.org/10.1016/S0925-5214(98)00073-3

Blankenship, S. M., Parker, M., & Unrath, C. R. (1997). Use of maturity indices for predicting poststorage firmness of Fuji apples. *HortScience*, 32 (5), 909-910. https://doi.org/10.21273/HORTSCI.32.5.909

Candir, E., Özdemir, A. E., & Aksoy, M. C. (2018). Effects of chitosan coating and modified atmosphere packaging on postharvest quality and bioactive compounds of pomegranate fruit cv. ‘Hicaznar’. *Scientia Horticulturae,* 235, 235-243. https://doi.org/10.1016/j.scienta.2018.03.017

Cantín, C. M., Crisosto, C. H., & Day, K. R. (2008). Evaluation of the Effect of Different Modified Atmosphere Packaging Box Liners on the Quality and Shelf Life of ‘Friar’ Plums. *HortTechnology hortte*, *18*(2), 261-265. https://doi.org/10.21273/HORTTECH.18.2.261

Champa, W. A. H., Gill, M. I. S., Mahajan, B. V. C., & Arora, N. K. (2014). Postharvest treatment of polyamines maintains quality and extends shelf-life of table grapes (*Vitis vinifera* L.*)* cv. flame seedless. *Postharvest Biology and Technology*, 91, 57-63. https://doi.org/10.1016/j.postharvbio.2013.12.014

Chien, S. H., & Chien, C. S. (2013). Effects of putrescine on the shelf life and quality of harvested fruits. *International Journal of Postharvest Technology and Innovation*, 3(1), 34-47. https://doi.org/10.1504/IJPTI.2013.052315

Coskun, S., & Askın, M. A. (2016). Bazı yerli elma çeşitlerinin pomolojik ve biyokimyasal özelliklerinin belirlenmesi. *Ziraat Fakültesi Dergisi*, 11 (1), 120 131.

Dibble, A. R. G., Davies, P. J., & Mutschler, M. A. (1988). Polyamine content of longkeeping Alcobaca tomato fruit. *Plant Physiology*, 86(2), 338-340. https://doi.org/10.1104/pp.86.2.338

El Ghaouth, A., Wilson C., & Wisniewski M. (2004). Biologically-based alternatives to synthetic fungicides for the control of postharvest diseases of fruit and vegetables. *Diseases of Fruits and Vegetables*, 511-535. https://doi.org/10.1007/1-4020-2607-2_14

Ennab, H. A., El-Shemy, M. A., & Alam-Eldein, S. M. (2020). Salicylic acid and putrescine to reduce post-harvest storage problems and maintain quality of murcott mandarin fruit, *Agronomy*, 10(1), 115. https://doi.org/10.3390/agronomy10010115

Erbas, D., Koyuncu, M. A., Ozusoy, F., & Onursal, C. E. (2018). Derim öncesi putresin uygulamasının 0900 Ziraat kiraz çeşidinin meyve kalitesi üzerine etkileri. *Akademik Ziraat Dergisi,* 7(2), 151-156. https://doi.org/10.29278/azd.476202

Fawole, O. A., Atukuri, J., Arendse, E., & Opara, U. O. (2020). Postharvest physiological responses of pomegranate fruit (cv. Wonderful) to exogenous putrescine treatment and effects on physico-chemical and phytochemical properties. *Food Science and Human Wellness*, *9*(2), 146–161. https://doi.org/10.1016/J.FSHW.2020.02.007

Guillen, F., Diaz-Mula, H. M., Zapata, P. J., Valero, D., Serrano, M., Castillo, S., & Martinez- Romero, D. (2013). Aloe arborescens and Aloe vera gels as coatings in delaying postharvest ripening in peach and plum fruit. *Postharvest Biology and Technology,* 83, 54-57. https://doi.org/10.1016/j.postharvbio.2013.03.011

Gunay, M., Karaca, H., & Kaya, A. (2021). Türkiye'de Elma Üretimi ve Ticaretinin Ekonomik Analizi. *Tarım Ekonomisi Araştırmaları Dergisi*, 35(4), 112-123.

Gunduz, K. & Ozdemir, E. (2003). Amik ovasında yüksek tünel ve açıkta yetiştirilen çileklerde renklenmenin objektif yöntemle belirlenmesi. *Türkiye IV. Ulusal Bahçe Bitkileri Kongresi*, 08-12 Eylül, 120-122, Antalya.

Hanif, A., Ahmad, S., Jaskani, M. J., & Ahmad, R. (2020). Papaya treatment with putrescine maintained the overall quality and promoted the antioxidative enzyme activities of the stored fruit. *Scientia Horticulturae*, 268, 109-367. https://doi.org/10.1016/j.scienta.2020.109367

Jawandha, S. K., Gill, M. S., Singh, N., & Gill, P. P. S. (2012). Effect of post-harvest treatments of putrescine on storage of mango cv. Langra. *African Journal of Agricultural Research,* 7(48), 6432-6436. https://doi.org/10.5897/AJAR12.1425

Jongsri, P., Rojsitthisak, P., Wangsomboondee, T., & Seraypheap, K. (2017). Influence of chitosan coating combined with spermidine on anthracnose disease and qualities of ‘*Nam Dok Mai*’ mango after harvest. *Sciantia Hortuculturae*, 222, 180-187. https://doi.org/10.1016/j.scienta.2017.06.011

Kader, A. A. & Yahia, E. M. (2011). Postharvest biology of tropical and subtropical fruits. In: Yahia, E.M. (Ed.). *Postharvest Biology and Technology of Tropical and Subtropical Fruits, Woodhead Publishing*, 79-111.

Kader, A. A., & Rolle, R. S. (2004). Modified atmosphere packaging and its effects on the quality of fresh fruits and vegetables. *Postharvest Biology and Technology*, 32(2), 123-142. https://doi.org/10.1016/j.postharvbio.2004.01.005

Kaur, M. & Kaur, A. (2019). Improvement in storability and quality of peach cv. Flordaprince with post-harvest application of various chemicals. *Journal of Pharmacognosy and Phytochemistry,* 8(1): 460-464.

Kaushal, M., Sharma, A., & Kaur, C. (2020). Effect of Modified Atmosphere Packaging on the Storage Quality of Apples. *Postharvest Biology and Technology*. 173, 1-8.

Khan, A. S., Singh, Z., Abbasi, N. A., & Swinny, E. E. (2008). Pre-or post-harvest applications of putrescine and low temperature storage affect fruit ripening and quality of "*Angelino*" plum. *Journal of Science Food Agriculture,* 88(10): 1686 1695. https://doi.org/10.1002/jsfa.3265

Khan, M. S., Zeb, A., Rahatullah, K., Ahmed, I. N., & Ahmed, S. (2013). Storage life extension of plum fruit with different colored packaging and storage temperatures. *IOSR Journal of Environmental Science Toxicology and Food Technology*, 7(3), 86-93. https://doi.org/10.9790/2402-0738693

Khosroshahi, M. R. Z., & Esna-Ashari, M. (2007). Post-harvest putrescine treatments extend the storage-life of apricot (*Prunus armeniaca* L.*)* 'Tokhm-sefid' fruit. *The Journal of Horticultural Science Biotechnology*, 82 (6), 986-990. https://doi.org/10.1080/14620316.2007.11512337

Kibar, H., Tas, A., & Gundogdu, M. (2021). Evaluation of biochemical changes and quality in peach fruit: effect of putrescine treatments and storage. *Journal of Food Composition and Analysis*, (102), 04048, 3-16. https://doi.org/10.1016/j.jfca.2021.104048

Kucuker, E., Aglar, E., Sakaldas, M., Sen, F., & Gundogdu, M. (2023a). Impact of postharvest putrescine treatments on phenolic compounds, antioxidant capacity, organic acid contents and some quality characteristics of fresh fig fruits during cold storage. *Plants (Basel, Switzerland)*, 12(6), 1291. https://doi.org/10.3390/plants12061291

Kucuker, E., Aglar, E., Gundogdu, M., Tekin, O., Ogurlu, F., & Kizgin Ozcengiz, C. (2023b). New approaches in fig preservation: use of melatonin to maintain postharvest quality of fig (*Ficus carica L.*) Fruit during cold storage. *Erwerbs-Obstbau*, *65*(6), 2585-2595. https://doi.org/10.1007/s10341-023-00958-w

Kucuker, E., Kuru Berk, S., Melda Colak, A., & Gundogdu, M. (2024). Melatonin use in post-harvest fruit physiology: effect of melatonin treatments on quality properties, primer and seconder metabolites contents of hawthorn fruit during cold storage. *Journal of Plant Growth Regulation*, 1-14. https://doi.org/10.1007/s00344-024-11522-5

Lownds, N. K., Banaras, M., & Bosland, P. W. (1993). Relationships between postharvest water loss and physical properties of pepper fruit (*Capsicum annuum* L.). *Hort Science*, 28(12), 1182-1184. https://doi.org/10.21273/HORTSCI.28.12.1182.

Mahto, R. & Das, M. (2013). Effect of gamma irradiation on the physico-chemical and visual properties of mango (*Mangifera indica* L.), cv. "*Dushehri*" and "*Fazli"* stored at 20°C. *Postharvest Biology Technology,* 86, 447-455. https://doi.org/10.1016/j.postharvbio.2013.07.018.

Malik, A. U., & Singh, Z. (2003). Abscission of mango fruitlets as influenced by biosynthesis of polyamines. *The Journal of Horticultural Science and Biotechnology*, 78(5), 721–727. https://doi.org/10.1080/14620316.2003.11511689

Mannozzi, C., Tylewicz, U., Chinnici, F., Siroli, L., Rocculi, P., Rosa, M. D., & Romani, S. (2018). Effects of chitosan based coatings enriched with procyanidin byproduct on quality of fresh blueberries during storage. *Food Chemistry,* 251, 18-24. https://doi.org/10.1016/j.foodchem.2018.01.015

Martinez-Ferrer M., Harper, C., Perex-Munnoz M., & Chaparro M. (2002). Modified atmosphere packaging of minimally processed mango and pineapple fruits. *Journal of Food Science,* 67, 3365–3371. https://doi.org/10.1111/j.1365-2621.2002.tb09592.x

Martinez-Romero, D., Alburquerque, N., Valverde, J. M., Guillen, F., Castillo, S., Valero, D., & Serrano, M. (2006). Postharvest sweet cherry quality and safety maintenance by Aloe vera treatments: a new edible coating. *Postharvest Biology and Technology,* 39, 93-100. https://doi.org/10.1016/j.postharvbio.2005.09.006

Ogurlu, F., Kucuker, E., Aglar, E., Kizgin Ozcengiz, C., & Uyak, C. (2024a). New approaches in pear preservation: Putrescine and modified atmosphere packaging applications to maintain fruit quality during cold storage. *Food Science & Nutrition*, 12(9), 6627-6636. https://doi.org/10.1002/fsn3.4290

Ogurlu, F., Kucuker, E., & Aglar, E. (2024b). Effects of *Aloe vera* and modified atmosphere packaging on the quality and biochemical properties of pear fruit during cold storage. *Applied Fruit Science*, *66*(3), 823-832. https://doi.org/10.1007/s10341-024-01070-3

Ozturk, B., & Aglar, E. (2019). Effects of modified atmosphere packaging (MAP) and AV treatments on quality characteristics of cornelian cherry fruits during cold storage. *Akademik Ziraat Dergisi,* 8(1), 1-8. https://doi.org/10.29278/azd.592897

Ozturk, B., Yildiz, M., Yildiz, K., & Gun, S. (2021). Maintaining the postharvest quality and bioactive compounds of jujube (*Ziziphus jujuba* Mill. Cv. 'Li'*)* fruit by applying 1-methylcyclopropene*. Scientia Horticulturae,* 275, 109671. https://doi.org/10.1016/j.scienta.2020.109671

Ozturk B. (2012). *Jonagold elma çeşidinde aminoethoksivinilglisinin (AVG) hasat önü dökümüne, 'Braeburn' elma çeşidinde metil jasmonatın (MEJA) renklenme üzerine etkileri.* [Doktora Tezi, Gazosmanpaşa Üniversitesi Fen Bilimleri Enstitüsü] Ulusal Tez Merkezi.

https://tez.yok.gov.tr/UlusalTezMerkezi/tezDetay.jsp?id=fXtWHf0EQsxy_1KKq6OTsw&no=X-ydWv7C6v7w6vL78DfV0g

Rojas-Graü, M. A., & Martín-Belloso, O. (2007). Effects of modified atmosphere packaging on the quality of fresh fruits and vegetables. *Food Research International*, 40(3), 263-271. https://doi.org/10.1016/j.foodres.2006.11.003

Sacks, E. J. & Shaw, D. V. (1994). Optimum allocation of objective color measurements for evaluating fresh strawberries. *Journal of the American Society for Horticultural Science jashs*, 119(2), 330-334. https://doi.org/10.21273/JASHS.119.2.330

Sandhya, S. (2010). Modified atmosphere packaging of fresh produce: current status and future needs. *LWT-Food Science Technology,* 43, 381-392. https://doi.org/10.1016/j.lwt.2009.05.018

Serrano, M., Martínez-Romero, D., Guillen, F., & Valero, D. (2003). Effects of exogenous putrescine on improving shelf life of four plum cultivars. *Postharvest Biology and Technology,* 30, 259-271. https://doi.org/10.1016/S0925-5214(03)00113-3

Sharma, R., Singh, D., & Singh, R. (2009). Biological control of postharvest diseases o fruits and vegetables by microbial antagonists: a review. *Biological Control*, 50(3), 205-221. https://doi.org/10.1016/j.biocontrol.2009.05.001

Sisler, E. C., & Serek, M. (2003). Putrescine and other polyamines in the regulation of fruit ripening. *HortScience*, 38(3), 589-593. https://doi.org/10.21273/HORTSCI.38.3.589

Song, H. Y., Jo, W. S., Song, N. B., Min, S. C., & Song, K. B. (2013). Quality change of apple slices coated with Aloe vera gel during storage. *Journal of Food Science*, 78(6), C817-C822. https://doi.org/10.1111/1750-3841.12141

Turk, R. & Karaca, H. (2015). Ülkemizde taze ürün depolayan soğuk muhafaza tesislerinde teknik ve ekonomik nitelikler. *12. Ulusal Tesisat Mühendisliği Sempozyumu Bildiriler Kitabı*, Makine Mühendisleri Odası Yayını, Ankara, ss.777-795.

Ustunel, M. A., Esturk, O. & Ayhan, Z. (2008). MAP'nin kirazın fiziksel özelliklerine (Renk ve Tekstür) etkisi. *Türkiye 10. Gıda Kongresi*, Erzurum, 241-244.

Valero, D., Martinez-Romero, D., & Serrano M. Riquelme F. (1998). Influence of post-harvest treatment with putrescine and calcium on endogenous polyamines, firmness and abscisic acid in lemon (*Citrus Lemon* L. Burm cv. Verna). *Jounal of Agriculture Food Chemistry*, 46 (6): 2102-2109. https://doi.org/10.1021/jf970866x

Wani, S. H., Khan, M. S., & Tufail, M. (2022). Postharvest Management of Apples: New Approaches to Reduce Quality Losses. *Horticultural Science*, 57(3), 157-165.

Zokaee Khosroshahi, M. R., & Esna-Ashari, M. (2007). Post-harvest putrescine treatments extend the storage-life of apricot (*Prunus armeniaca* L.) 'Tokhm-sefid' fruit. *The Journal of Horticultural Science and Biotechnology*, 82(6), 986–990. https://doi.org/10.1080/14620316.2007.11512337

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Effects of external gibberellin on germination of wall-spray cotoneaster seeds stratified with and without fruit under dry-cold conditions

Hüseyin ÇELİK[1]*, Öznur KALAYCI KARASAKAL[2]

[1]Ondokuz Mayıs University, Agricultural Faculty, Department of Horticulture, Samsun, Türkiye
[2]Ondokuz Mayıs University, Institute of Postgraduate Education, Samsun, Türkiye

***Corresponding author e-mail:** huscelik@omu.edu.tr

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Abstract: Wall-spray cotoneaster (*Cotoneaster horizontalis* Decne.) seeds show deep dormancy and have a very low germination rate. Wall-spray cotoneaster seeds were dry cold stratified (+4°C) either in the fruit or removed from the fruit for different periods (0, 30, 60, 90, 120 and 180 days) and then treated with different GA_3 doses (0, 500, 1000 and 2000 ppm) and sown in peat medium in bottom heated (+24°C) trays in the greenhouse in the current study. The effects of GA_3 treatment on germination (emergence) rate, living plant rate (%), plant height (cm) and leaf number were determined. The highest germination rate (35.00%) was obtained from the seeds treated with 2000 ppm GA_3 without cold stratification. These control seeds were kept in fruit between October and May under room temperature. The germination rate in the seeds treated with 1000 ppm GA_3 after stratification in dry cold at +4°C for 60 days in the fruit was only 25.00%. The GA_3 applications did not affect the germination rate of the seeds that were taken out of the fruit and stratified in dry-cold for different periods.

Keywords: Cotoneaster, seed, dry-cold, GA_3, germination

Meyve içinde ve dışında kuru soğukta katlanan yayılıcı dağ muşmulası tohumlarında çimlenme üzerine giberellinin etkisi

Öz: Yayılıcı dağ muşmulası tohumları derin dinlenme gösterir ve çimlenme oranı da çok düşüktür. Bu çalışmada, yayılıcı dağ muşmulası (*Cotoneaster horizontalis* Decne.) tohumları katlanmadan (kontrol) ve 30, 60, 90, 120 ve 180 gün +4°C'de meyve içinde ve meyveden çıkarılarak kuru soğukta katlandıktan sonra 0ppm (kontrol) ile 500, 1000 ve 2000 ppm GA_3 ile muamele edilmiştir. Soğukta katlanarak gibberellin uygulanan tohumlar +24°C'lik alttan ısıtmalı tavalardaki torf ortamına ekilerek çimlenme (çıkış) oranı, yaşayan bitki oranı (%), bitki boyu (cm) ve yaprak sayısı tespit edilmiştir. En yüksek çimlenme oranı %35.00 ile soğukta katlanmadan 2000 ppm GA_3 uygulandıktan sonra ekilen tohumlardan elde edilmiştir. Bu tohumlar oda şartlarında ekim-mayıs arasında meyve içinde bekletilmiştir. Meyve içinde 60 gün +4°C'lik kuru soğukta katlandıktan sonra 1000 ppm GA_3 uygulandıktan sonra ekilen tohumlardaki çimlenme oranı ise %25.00'e kadar çıkabilmiştir. Meyveden çıkarılarak kuru-soğukta farklı sürelerde katlanan tohumlarda çimlenme üzerine GA_3 uygulamaları ise etki etmemiştir.

Anahtar kelimeler: Cotoneaster, çekirdek, kuru-soğuk, GA_3, çimlenme

1. Introduction

Cotoneaster species (*Rosaceae* family) constitute a very important part of ornamental plants in shrub form. They have attractive plant characteristics and are used in landscape planning. *Cotoneaster* plants can be tall or show horizontal or sprayed growth with multi-colored fruits and leaves. Their leaves turn red, orange or yellow in autumn. There are nearly 400 species in the *Cotoneaster*, which includes plants native to temperate climates in Asia. The wall-spreading *Cotoneaster* (*Cotoneaster horizontalis* Decne.), has horizontal branches and grows 50-60 cm height. Although it is native to western China, it is widely used in outdoor arrangements in Türkiye and many countries in Europe due to its blue-green leaves in summer and its dense fruits in winter and fall. It is one of the most valuable shrubs, often used in rock gardens, on roadside slopes, small hillsides and flowering herb gardens. *Cotoneaster* is also considered as a ground cover and used for creating fences, shelter for wild birds and rodents and

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fruiting plants for their feeding. It is good for wind blocking, solitary plant in the landscape by forming abundant flowers, barrier and corridor forming plants for roadsides and area isolation in urban landscapes (Buffin, 2005; Ölmez et al., 2006; Ölmez et al., 2007; Lonnee et al., 2011). It is an attractive landscape plants in all seasons with its plant, flowers and fruits, is easy to maintain, can take different forms with pruning and prefers sunny places all day long. *Cotoneaster* fruits contain one to five seeds (Slabaugh & Shaw, 2008). Cotoneaster seeds have very hard endocarp and seed coats, they physically show deep and double dormancy and the embryo remains physiologically dormant over years (Baskin & Baskin, 2004; Hartmann et al., 2014). According to studies, cold-stratification for up to 24 months may be required for seed propagation of *Cotoneaster* (Bujarska-Borkowska & Suszka, 2019). Hot and/or cold stratification for 2-3 months and scarification with intense sulfuric acid before cold stratification is required for germination of cotoneaster seeds (Tilki, 2013). Aygün et al. (2011) stated that germination rate was just 41.00% of *Cotoneaster horizontalis* seeds stratified at 60 days in wet and cold conditions. They also found that gibberellins and sulfuric acids did not affect the germination rate.

Seed propagation is becoming increasingly popular in ornamental plants. Because propagation by cuttings is much more expensive. There are differences between plant species in terms of seed viability and the storage period of seeds can be short. It is very important for seedling producers that ornamental plants used in landscaping can be propagated by seeds and intensively. It is important to eliminate dormancy and germination prevent substances in the seed propagated plants. Hard and thick seed coats also prevent seed germination. Many factors in the seed endosperm, embryo or coats are effective on germination. They may inhibit germination and affect seed development, gas exchange and water mobility in different ways. To eliminate these factors scarification, cold storage, hot or cold-water applications, acid treatment and plant growth regulators can be used (Karam et al., 2001; Persson et al., 2006; Slabaugh et al., 2008; Liu et al., 2010; Lonnee et al., 2011; Nadeem et al., 2013; Tilki, 2013; Hartmann et al., 2014). While some *Cotoneaster* seeds can show high germination under cold and white light (Tilki, 2013), pre-sowing gibberellic acid treatments gave similar results to the light effect. In addition, since *Cotoneaster* seeds have a hard shell, keeping them in a cool environment and treatment with surface abrasives may affect the germination rate. According to Tilki (2013), some researchers obtained 67.00% germination rate after stratified *Cotoneaster horizontalis* seeds in cold for 11 months and treating them with sulfuric acid. Researchers reported that *Cotoneaster* seeds have a long dormancy with low germination rate. Their seeds have also double dormancy due to hard and impermeable seed coats and embryo physiology (Aygün et al., 2011; Hartman et al., 2014; Zare, 2019). *Cotoneaster* fruits for seed collection can be collected in early fall and after leaf fall by hand scraping or shaking. Fruit firmness and color can be used for maturity (Slabaugh & Shaw, 2008). Hartmann et al. (2014) stated that *Cotoneaster* species have fleshy fruits and the seed is preserved in dry fruits. Seeds of some *Cotoneaster* species can emerge without resting if they are stratified for 115 days and can germinate in a warm environment. It is stated that even in seeds stratified for about three months, there is conditional dormancy and they can germinate better at temperatures of 15-25°C. In some studies, it was also found that *Cotoneaster* seeds that were not stratified or kept in the cold for 60 days were not affected by the ambient temperature and did not germinate. It is also reported that when *Cotoneaster* seeds are kept in sulfuric acid for 1.5 hours and then stratified in a humid environment at +4°C for 3-4 months, the negative effects of impermeable shells on germination may decrease (Hartmann et al., 2014). According to Zare (2019), *Cotoneaster nummularioides* seed germination was 18.30% after sulfuric acid-potassium nitrate treatment and 4 months cold stratification. He revealed that chilling without scarification of the cotoneaster seeds had no germination.

In this study, the effects of dry-cold stratification of wall-spray cotoneaster seeds stratified with or without fruits and gibberellic acid applications on germination were investigated.

2. Materials and Methods

2.1. Obtaining seeds and cold stratification

The seeds of the wall-spray cotoneaster used in the experiment were taken from the fruits of *Cotoneaster horizontalis* Decne. plants. The fruits collected in the first week of November. The large seeds were selected after separation from the pericarp and subjected to a floating test and kept at room temperature for 10 days until they reached 10% moisture content. The 100 seeds were filled into perforated and zip lock bags and kept in cold storage at +4°C for different periods (30, 60, 90 and 120 days). Control and cold stratified seeds were kept in the dark room conditions until sowing. The seeds that will be cold-stratified in the fruit and at +4 °C were transferred to cold storage by filling them into zip lock and perforated bags without removing them from the fruit, and the seeds that will not be cold-stratified in the fruit were kept under dark room conditions until sowing. The fruits that were kept in the cold storage were removed and the seeds were removed from the fruits, washed, dried and filled in perforated and locked bags with holes so that 100 seeds per bag and kept in room conditions and in a dark environment until sowing.

2.2. Gibberellic acid (GA_3) treatment

The seeds of wall-spray cotoneaster, which were removed from the fruit and stratified in dry-cold conditions, were kept in 500, 1000 and 2000 ppm GA_3 solution for 24 hours before sowing. The seeds of the control group (0 ppm), which were not treated with GA_3, were kept in pure water for 24 hours. After treatment, the seeds removed from the GA_3 solution were sown in peat in the greenhouse and in trays with a constant bottom heating temperature of +24°C. The seeds were removed from the fruits after cold stratification. They kept in room conditions for 10 days until they reached 10% humidity. Then they filled in perforated and zip locked bags and kept in 500, 1000 and 2000 ppm GA_3 solution for 24 hours. The seeds of the control (0 ppm GA_3) were kept in pure water for 24 hours. GA_3-treated seeds were sown in trays had peatmoss under greenhouse with a bottom heating temperature of +24°C at the end of April. Fungicides were applied weekly against fungal diseases in the seed sowing trays, irrigation was applied, and the environment was humidified by controlling the misting system with a "leaf wetness sensor" so that the ambient humidity was above 60% after emergence started (Klingaman, 2015).

2.3. Determination of germination rate (%) and transplanting the seedlings

For the beginning of germination in the seeds sown in peat in bottom heated trays under greenhouse, the first date when the cotyledon leaves started to emerge on the peat surface was taken into consideration. After this date, weekly germination (emergence) was determined by counting the seeds that emerged weekly for 6 weeks and total germination rate (%) was determined over all emerged seedlings. At the end of six weeks (Pittcock, 2015), emergence was completed and when the plantlets reached the four-leaf stage, they were removed from the trays and transplanted to the P9 plastic pots (9x9x9 cm dimensions) including garden soil+barnyard manure+sand (1:1:1, v/v) at the end of September. The plants were maintained in the greenhouse for 6 months and the survival rate was determined. Plant height and number of leaves were also determined weekly.

2.4. Statistical analyses

The experiment, which was established in 3 replications with 100 seeds in each replicate in bottom-heated (+24°C) trays in the greenhouse, was designed according to the "split plots experimental design divided by blocks of coincidence". Here, the stratification type (inside the fruit, outside the fruit) was randomly allocated to the main plots, cold storage period (0, 30, 60, 90, 120 and 180 days) to the sub-plots and GA_3 doses (0, 500, 1000 and 2000 ppm) to the sub-sub-plots. Angle (arcsin$\sqrt{x}$) transformation was applied to the "%" data obtained from the experiment and statistical analyses were performed on these data. Statistical analyses of the data obtained from the experiment were performed using SPSS V25.0 software (SPSS Inc., USA) based on 3-factor analysis of variance (ANOVA). Differences between the mean values were evaluated by Duncan Multiple Range Test. In the statistical evaluation of the results, the significance level between the differences was expressed as significant at $P<0.05$ level.

3. Results and Discussion

The results of the effects of stratification type, duration and GA_3 doses on germination and survival rates (%), seedling height and number of leaves in wall-spread cotoneaster seeds are given in Table 1. According to the findings, the effects of all factors on the criteria examined in the seeds of spreading cotoneaster kept in the cold with the fruit or removed from the fruit were found to be significant. The best germination rate (35.00 %) observed from 2000 ppm GA_3 applied seeds which were not cold stratified but kept inside the fruits under room conditions between October and May till sowing. It was determined that the germination in the seeds which were kept in dry cold at +4°C for 60 days without removing from the fruit and then treated with 1000 ppm GA_3 could reach up to 25.00% (Table 1).

As the stratification period in fruit increased, the efficiency of GA_3 application decreased. In the seeds of wall-spray cotoneaster that were kept in fruit and under room conditions until planting, i.e. that were not treated with cold, 0 ppm GA_3 application showed 27.33% germination success, while there was no germination in the 500 ppm GA_3 application. The germination which was 17.33% at 1000 ppm increased to 35% at 2000 ppm. This situation proves the research results indicating that the germination in wall-spray cotoneaster seeds is irregular. In wall-spray cotoneaster seeds, the efficiency of GA_3 application decreased as the stratification period in the fruit and under cold increased, only the seeds cold-stratified for 30 and 180 days and no GA_3 applied gave germination results (16.33% and 22.67%, respectively) and 1000 ppm GA_3 application showed 25.00% germination in cold-stratified seeds for 60 days. In cotoneaster seeds kept in the fruit and in the cold for 120 days, only 11.66% germination was achieved with 500 ppm GA_3 application. The remaining seeds kept in the fruit and in the cold and applied with GA_3 did not germinate (Table 1). After being removed from the fruit and cold stratified, the germination in the seeds to which GA_3 was applied did not increase, and only the control groups germinated. Accordingly, the germination in the seeds that were not kept in the cold outside the fruit and that were not applied GA_3 was 5.33%. While the germination in the seeds that were cold stratified for 30 days outside the fruit was 3.33% at 0 ppm. The seeds that were cold stratified for 60 and 120 days without any GA_3 application showed a germination success of 2.33%. The seeds that were cold stratified for 180 days outside the fruit and that were not applied GA_3 had the lowest germination rate with 1.67%. It was also determined that most of the seeds that were kept in the cold outside the fruit and for different periods and applied GA_3 did not germinate at all (Table 1). When the average values were taken into consideration, it was determined that the seeds that were not stratified reached the highest values in terms of germination, survival rate, plant height and leaf number in terms of stratification period. It was determined that 60 days of cold stratification came second in germination and survival rates, and 120 days of cold storage came second in plant height and leaf number (Figure 1a). When GA_3 doses were considered, 0 ppm GA_3 application as control dose came first in all criteria, while 1000 ppm GA_3 followed, but the results obtained were very low (Figure 1b). In the stratification type, it was determined that germination and survival rates and plant height were better in seeds stratified in the fruit, while leaf number gave similar results in both stratification types (Figure 1c).

According to the stratification type, duration and GA_3 applications, all plants that germinated and emerged to the soil surface and were transplanted after the formation of true leaves had the same survival rate. Accordingly, the highest survival rate, as in the germination rate, was obtained from the seeds kept in the fruit and kept in room conditions until planting (October-May) and to which 0 ppm GA_3 was applied, with 35.00%. The lowest survival rate, with 1.67%, was obtained from the seeds kept outside the fruit and kept dry-cold in +4°C for 180 days and again to which 0 ppm GA_3 was applied. The highest value in terms of plant height was determined as 25.67 cm in the plants that grew from the seeds kept outside the fruit and kept in cold for 60 days and not to which GA_3 was applied. The number of leaves reached the highest value with 28.33 in the seeds kept in the fruit and kept in room conditions and to which 2000 ppm GA_3 was applied (Table 1). In our study, it was found that the hard and impermeable shells in the seeds of the wall spreading cotoneaster had a negative effect on germination, and the germination success was very low even after the seeds were stratified in the cold and GA_3 was applied. The fact that the germination rates obtained from previous germination experiments involving chemical scarification were slightly higher than the results of our study. This may be since we did not erode the hard coats of the seeds with acids. Therefore, it may be necessary to use scarified chemicals together with GA_3 application in addition to dry or moist cold stratification in spreading cotoneaster. Because species in the genus *Cotoneaster* produce seeds with hard and impermeable shells, and the embryo in these seeds has double dormancy due to its physiological characteristics. Seed germination of this species can be increased by wet cold stratification, scarify with acid and soaking in hot water (Slabaugh & Shaw, 2008; Lonnee et al., 2011). The addition of some commercial activators to wet and cold soaking can also increase germination (Hartmann et al., 2014). The duration of pre-treatments affecting germination in seeds may vary according to plant species, seed type and the environment. Region and years in which the seeds were taken due to shell thickness differences and the degree of resting in the embryo is also important. Because some researchers applied concentrated sulfuric acid to the seeds of spreading cotoneaster for 90 min and kept at +2°C cold and wet. On the other hand, germination in cotoneaster seeds is inconsistent and rapid germination is very difficult to achieve (Tilki, 2013). Slabaugh & Shaw (2008) showed that increasing the germination rate in cotoneaster seeds depends on soaking them in sulfuric acid for 3 hours and then keeping them in hot water at +27°C for 48 hours. Zare (2019) resolved the dormancy problem of Cotoneaster seeds under the combined effects of scratches shell and cold stratification.

The germination rate in cotoneaster seeds varied depending on the activators used. Bujarska-Borkowska & Suszka (2019) obtained 48% germination on stratified the wall-spray cotoneaster seeds in hot-cold environments and scarified them with sulfuric acid. In our experiment, where scarifying was not used, the germination rate was up to 35.00% when 2000 ppm GA_3 was applied to the seeds that were not stored in the fruit and in the cold. On the other hand, Slabaugh & Shaw (2008) germinated wall-spray cotoneasters in sand and found that the seeds that were applied at 30°C during the day and 20°C at night germinated at a rate of 30.00% in 100 days. Zare (2019) resolved the problem dormancy Cotoneaster under the combined effects of scratches shell and cold stratification, but the highest germination rate was just 18.20% and lower than our findings. However, Aygün et al. (2011) found 41.00% germination rate of Cotoneaster horizontalis seeds and this may cause from cold and wet stratification.

Table 1. Variation of germination rate (%), survival rate (%), plant height (cm) and number of leaves in wall-spray cotoneaster seeds stored with or without fruit and kept in dry cold according to stratification duration and GA_3 application.

Stratification type	Stratification day	GA_3 (ppm)	Germination rate (%)	Mortality rate (%)	Plant height (cm)	Leaf number
With fruit	0	0	27.33 b	27.33 b	21.66 bc	16.33 cde
		500	0.00 e	0.00 e	0.00 f	0.00 f
		1000	17.33 cd	17.33 cd	12.33 e	14.66 de
		2000	35.00 a	35.00 a	16.00 de	28.33 a
	30	0	16.33 cd	16.33 cd	16.67 de	19.50 c
		500	0.00 e	0.00 e	0.00 f	0.00 f
		1000	0.00 e	0.00 e	0.00 f	0.00 f
		2000	0.00 e	0.00 e	0.00 f	0.00 f
	60	0	0.00 e	0.00 e	0.00 f	0.00 f
		500	0.00 e	0.00 e	0.00 f	0.00 f
		1000	25.00 bc	25.00 bc	21.67 bc	18.00 cd
		2000	0.00 e	0.00 e	0.00 f	0.00 f
	120	0	0.00 e	0.00 e	0.00 f	0.00 f
		500	11.66 d	11.66 d	19.33 cd	19.33 c
		1000	0.00 e	0.00 e	0.00 f	0.00 f
		2000	0.00 e	0.00 e	0.00 f	0.00 f
	180	0	22.67 bc	22.67 bc	18.33 d	18.33 cd
		500	0.00 e	0.00 e	0.00 f	0.00 f
		1000	0.00 e	0.00 e	0.00 f	0.00 f
		2000	0.00 e	0.00 e	0.00 f	0.00 f
Without fruit	0	0	5.33 de	5.33 de	21.67 bc	20.67 bc
		500	0.00 e	0.00 e	0.00 f	0.00 f
		1000	0.00 e	0.00 e	0.00 f	0.00 f
		2000	0.00 e	0.00 e	0.00 f	0.00 f
	30	0	3.33 e	3.33 e	22.67 bc	23.50 bc
		500	0.00 e	0.00 e	0.00 f	0.00 f
		1000	0.00 e	0.00 e	0.00 f	0.00 f
		2000	0.00 e	0.00 e	0.00 f	0.00 f
	60	0	2.33 e	2.33 e	25.67 a	24.00 b
		500	0.00 e	0.00 e	0.00 f	0.00 f
		1000	0.00 e	0.00 e	0.00 f	0.00 f
		2000	0.00 e	0.00 e	0.00 f	0.00 f
	120	0	2.33 e	2.33 e	19.33 cd	21.50 bc
		500	0.00 e	0.00 e	0.00 f	0.00 f
		1000	0.00 e	0.00 e	0.00 f	0.00 f
		2000	0.00 e	0.00 e	0.00 f	0.00 f
	180	0	1.67 e	1.67 e	14.33 d	14.00 de
		500	0.00 e	0.00 e	0.00 f	0.00 f
		1000	0.00 e	0.00 e	0.00 f	0.00 f
		2000	0.00 e	0.00 e	0.00 f	0.00 f

* There is no statistical difference between the data shown with the same letter in the columns, $p<0.05$.

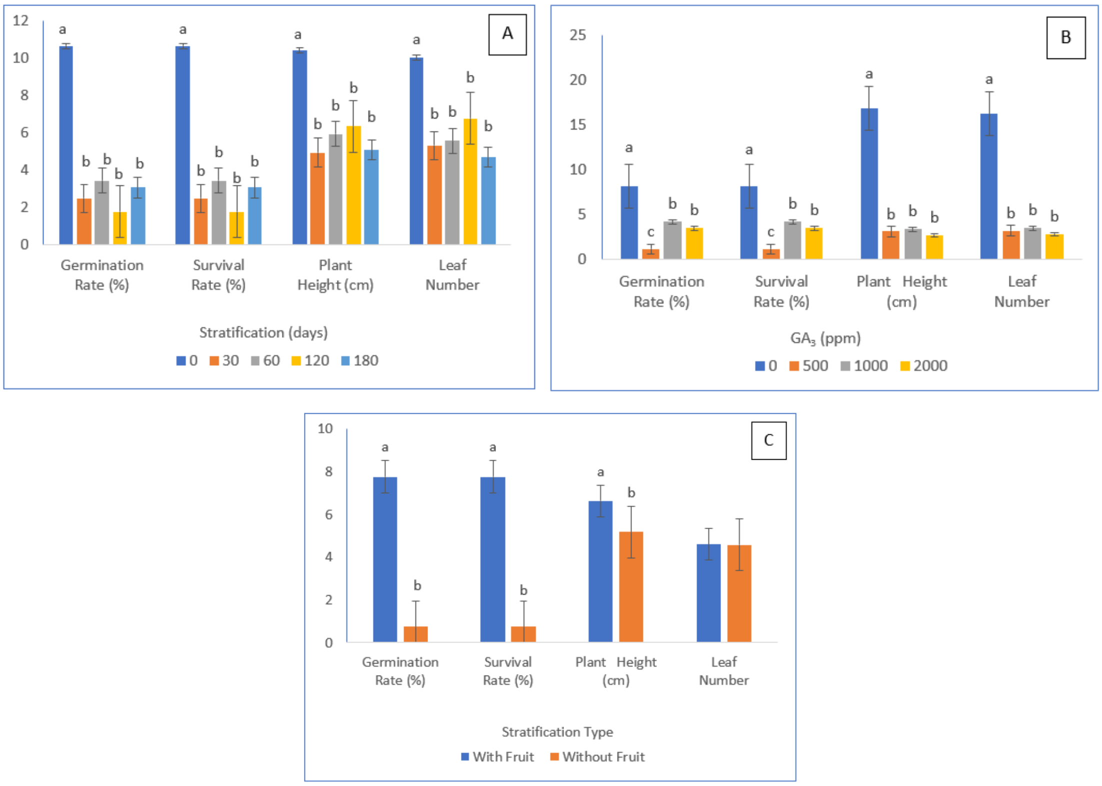

Figure 1. Changes of germination rate (%), survival rate (%), plant height (cm) and leaf number in wall-spray cotoneaster seeds stored in dry-cold with or without fruit, according to stratification period (A), GA_3 doses (B) and stratification type (C).

As can be seen, the germination rate in wall-spray cotoneasters is unstable and inconsistent. The low germination rate obtained in our study may also be due to environmental conditions, plant growth and development, and the characteristics of the place where the seeds were collected. Because environmental conditions can affect the end of seed dormancy and germination capacity. The most promising way to understand this phenomenon is to examine not only morphological characters but also physiological diversity of seeds together with plant taxonomy, ecology and geographical factors (Hartmann et al., 2014). Important factors include photoperiod, temperature and light intensity in seed maturation. Germination rates in species of the *Cotoneaster* genus may vary depending on the species, and it is stated that stratification of seeds in cold-hot conditions, abrasion of the seed coat, soaking in hot water and light in the germination environment may also be effective (Slabaugh and Shaw 2008; Lonnee et al., 2011; Tilki, 2013; Hartmann et al., 2014). Cotoneaster seeds have thick and very hard shells and stratification and chemical abrasion are carried out in cold and humid environments. In addition, double dormancy and excessive germination inhibitory substances prevent their germination (Hartman et al., 2014). On the other hand, some Cotoneaster species can germinate in light and GA_3 treatment can create a light effect (Tilki, 2013). This situation is also stated by Slabaugh & Shaw (2008) and they state that the ambient temperature should be high for germination. In this experiment, germination success may have decreased because the seeds were kept in dry cold. However, the germination rate is low in dispersing cotoneasters (Slabaugh & Shaw, 2008) and the pretreatments for germination, their duration, the thickness of the seed coats and the degree of embryonic dormancy should also be taken into account (Liu et al., 2010; Hartmann et al., 2014).

4. Conclusion

Wall-spray cotoneaster (*Cotoneaster horizantalis* Decne.) is an ornamental plant in the *Rosaceae* family and widely used in outdoor arrangements. In recent years, it has been necessary to study this species generatively and vegetatively in order to respond to the increasing plant demands. For this purpose, the effectiveness of GA_3 treatment in addition to dry cold stratification of seeds in and out of the fruit on germination and seedling quality in seed propagation, which is a rapid and intensive propagation method, was investigated. The highest germination rate in wall-spray cotoneaster seeds was obtained with 35.00% in those kept in the fruit, not treated with cold but treated with 2000 ppm GA_3. The germination rate in all other applications remained below this value, and in fact, there was no germination in most applications. The germination and survival rate of seeds that were not treated with GA_3 were higher than the others among the seeds that were stratified both with the fruit and by removing them from the fruit. The survival rate in germinated and transplanted plants gave the same result in all applications. According to the average values, no or 60 days stratification, no GA_3 or and 1000 ppm GA_3 treatment and stratification the seed inside the fruits has come to the fore. All the results showed that the germination success of the wall-spray cotoneaster, especially without using different scarification of the hard and impermeable shells, may be very low. Therefore, after treatment with some plant growth regulators to break the dormancy in spreading cotoneaster (*Cotoneaster horizontalis* Decne.) seeds, several applications such as seed shell corrosive chemicals, light, germination medium ingredients, pH and EC value, temperature and humidity should be investigated.

Conflict of interest

The authors declare no conflicts of interest.

Authorship contribution statement

H.Ç: Methodology, Planning and conducting the experiment, performing statistical analyses, writing-original draft preparation, writing- reviewing and editing. Ö.K.K: Conducting the experiment, taking observations and measurements.

References

Aygün, C., Olgun, M., Sever, A.L., Kara, İ., Erdoğdu, İ & Atalay, A.K (2011). Evaluation of germination of different shrubs by some methods. *Biological Diversity and Conversation,* 4(3), 53-57

Baskin, J.M. & Baskin, C.C. (2004). A classification system for seed dormancy. *Seed Science Research* 14, 1–16.

Buffin, M.F. (2005). *Winter-Flowering Shrubs.* Timber Press, 232.

Bujarska-Borkowska, B. & Suszka, J. (2019). Seed dormancy breaking under controlled conditions in ornamental *Cotoneaster spp*. *Dendrobiology*, 81, 97–104 http://dx.doi.org/10.12657/denbio.081.011

Hartmann, H.T., Kester, D.E., Davies, F.T. & Geneva, R.T. (2014). *Plant Propagation. Principles and Practices*. Pearson New Int. Ed. England, Eight Ed., 922p.

Karam, N. M. & Al-Salem, M.M. (2001). Breaking dormancy in Arbutus andrachne L. seeds by stratification and gibberellic acid. *Seed Science and Technology*. 29, 1, 51-56.

Klingamana, G.L. (2015). *Propagation Structures. Types and management*. In: *Plant Propagation Concepts and Laboratory Exercises, SE.*, 109-121p, Eds: Caula A. Beyl and Robert N. Trigiano. CRC Press, Taylor & Francis Group.

Liu, Q., Lan, Q.-Y., Tan, Y.-H., Shen Y.-X. & Wen, B. (2010). A preliminary study on seed germination of dominant plants from a karst landscape in bijie, guizhou. *Chinese Academy of Sciences* 32(6), 539-546.

Lonnee, D., Rose, D., Selinger, D. & Whitman, J. (2011). *Growing Shrubs and Small Trees in Cold Climets.* Univ. Of Minnesota Press., 81-84.

Nadeem, M., Riaz, A., Younis, A., Akond, M., Farooq, A. & Tariq, U. (2013). Improved technique for treating seed dormancy to enhance germination in *Rosa × hybrida. Turkish Journal of Botany,* 37:521-529

Ölmez, Z., Göktürk, A. & Temel, F. (2007) Effects of some pretreatments on seed germination of nine different drought-tolerant shrubs. *Seed Science and Technology* 35, 75–87.

Ölmez, Z., Temel, F., Göktürk, A., & Yahyaoğlu, Z. (2006) Effect of cold stratification treatments on germination of drought tolerant shrubs seeds. *J. of Environmental Biology.* 28 (2 suppl.): 447–453.

Persson, L., Jensen, M., Eriksen, E. N. & Mortensen, L.C. (2006). The effect of endocarp and endocarp split in resistance on warm stratification requirement of hawthorn seeds (*Crataegus monogyna*). *Seed Science and Technology*, 34(3), 573-584.

Pittcock, J.K. (2015). *Seed Production, Processing and Analysis. In: Plant Propagation Concepts and Laboratory Exercises, SE.*, 419-425, Eds: Caula A. Beyl and Robert N. Trigiano. CRC Press, Taylor & Francis Group.

Slabaugh, P.E. & Shaw, N.L. (2008). *Cotoneaster* Medik.: cotoneaster: *The woody plant seed manual* (ed. by FT Bonner & RP Karrfalt) Agriculture Handbook 727, 442–446.

Tilki, F. (2013). Seed germination of *Cotoneaster nummularia* as influenced by scarification, stratification, temperature and light. International Science and Technology Conference June 25–27. Rome, Italy, pp. 207–213.

Zare, A. (2019). Effect of cold stratification and chemical scarification duration on germination of Cotoneaster nummularioides Pojark. *Journal of Plant Research (Iranian J. of Biology)*, 32(2), 353-362.

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Comparison of kinetics, energy consumption, and *GHG* analysis of Santa Maria variety pear chips processed by microwave and hot air-assisted microwave drying systems

Muhammed TAŞOVA[1]*, Süreyya AYVALIOĞLU[1]

[1]Tokat Gaziosmanpaşa University, Faculty of Agriculture, Department of Biosystems Engineering, 60250, Tokat, Türkiye

***Corresponding author e-mail:** muhammed.tasova@gop.edu.tr

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Abstract: This study, evaluated the effects of microwave-*MD* and hybrid-*MACD* (hot air + microwave) drying systems on drying rate (*DR)*, moisture content (*MR)*, effective moisture diffusion (D_{eff}), specific moisture absorption rate (*SMER)*, specific energy consumption (*SEC)*, and greenhouse gas emission (*GHG)* properties in the production process of '*Santa Maria'* variety pear fruit chips. Microwave method (except 360 W) dried the products in a shorter time than the hybrid method. The *DR* values of the *MD* method were higher than *MACD*. The D_{eff} values of the drying processes varied between 2.54 × 10^{-9} and 1.01 × 10^{-8}. The average *SMER* values for the *MD* method varied between 0.006917 - 0.002803 kg/kWh and the *SEC* values varied between 356.8205 - 144.5714 kWh/kg. For *MACD* method, the average *SMER* values varied between 0.0037 - 0.0016 kg/kWh and *SEC* values between 6261.5 - 2693.6 kWh/kg. The increase in energy consumption increased the *GHG* values. The lowest *GHG* values were determined in the drying process performed at *MD* - 720 W power value.

Keywords: Pear fruit, drying processes, effective moisture diffusion, energy analyses, greenhouse gas

Mikrodalga ve sıcak hava destekli mikrodalga kurutma sistemleriyle işlenen Santa Maria çeşidi armut cipslerin kinetik, enerji tüketimi ve sera gazı analizinin karşılaştırılması

Öz: Bu çalışmada, mikrodalga (*MD)* ve hibrit (*MACD)* (sıcak hava + mikrodalga) kurutma sistemlerinin, '*Santa Maria'* çeşidi armut meyve yongalarının üretim sürecinde kurutma hızı (*DR)*, nem içeriği (*MR)*, etkili nem difüzyonu (D_{eff}), özgül nem çekme oranı (*SMER)*, özgül enerji tüketimi (*SEC)* ve sera gazı emisyonu (*GHG)* özellikleri üzerine etkileri incelenmiştir. Kurutma prosesleri arasında mikrodalga yöntemi (360 W hariç) hibrit yönteme göre ürünleri daha kısa sürede kurutmuştur. *MD* yönteminin *DR* değerlerinin *MACD* yönteminden daha yüksek olduğu bulunmuştur. Kurutma proseslerinin D_{eff} değerleri 2.54 × 10^{-9} ile 1.01 × 10^{-8} arasında değişmiştir. *MD* yöntemi için ortalama *SMER* değerleri 0,006917 - 0,002803 kg/kWh arasında, *SEC* değerleri ise 356,8205 - 144,5714 kWh/kg arasında değişmiştir. *MACD* yöntemi için ortalama *SMER* değerlerinin 0,0037 - 0,0016 kg/kWh arasında, *SEC* değerlerinin ise 6261.5 – 2693.6 kWh/kg arasında değiştiği belirlenmiştir. Enerji tüketimindeki artış *GHG* değerlerini artırmıştır. En düşük *GHG* değerleri *MD* - 720 W güç değerinde gerçekleştirilen kurutma prosesinde belirlenmiştir.

Anahtar kelimeler: Armut meyvesi, kurutma işlemleri, efektif nem difüzyonu, enerji analizleri, sera gazı

1. Introduction

Drying is the process of removing moisture from solid or semi-solid material by evaporation technique (Aghbashlo et al., 2008). The process of removing water from products/dehydrating them to preserve for human food is one of the oldest known methods (Antonio et al., 2008). Minimium nutritional losses, quick drying, and low energy consumption are the desired standards for achieving this goal (Afzal et al., 1999). For this reason, drying methods and techniques have been developed.

The most commonly used drying methods are conventional (tray, tunnel, and drum etc.), microwave and microwave-assisted (oven, vacuum etc.) hybrid techniques (Kutlu et al., 2015). The most widely used drying technique in the fruit and vegetable drying

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industry is hot air-drying systems. These systems, transmit hot air to the drying medium, and constitute > 85% of the drying devices used in the drying field (Moses & Authority, 2014). Hot air-drying systems have the advantage of not being affected by climatic conditions. However, the long drying process causes nutritional losses (Guan et al., 2024). Understanding of good drying has improved with the development of innovative drying systems. This has revealed the importance of sustainable food systems (Calín-Sánchez et al., 2020). However, the drying time has decreased by an average of 26%, the process efficiency has increased, and the energy consumption has decreased by approximately 80% (Chojnacka et al., 2021). Microwave drying ovens are one of the innovative drying systems used in the drying processes developed by utilizing microwave energy (Fan et al., 2024). Microwave energy penetrates the moisture in the fresh product and heat is produce by the principle of ionic contact and polar rotation (Li et al., 2023). Junqueira et al. (2017) dried the pumpkin to compare the convective and microwave drying systems. The microwave method dried the product earlier than the convective drying system. Although microwave drying systems have advantages over many other methods, there are still some quality losses in the product due to high heat towards the final stage of drying (Shen et al., 2020). Microwave-assisted drying methods have been developed to eliminate the problems that occur in microwave drying methods. The quality of food materials is better when compared to the drying systems used together (hybrid). For this reason, researchers have focused on investigating the properties, effects and advantages of microwave-assisted hybrid drying methods (Zielinska et al., 2020). There are some studies in the literature on the production of dried pear fruit by applying microwave and different drying techniques. For example, Önal et al. (2021) dried Rocha variety pear fruit using ultrasound and microwave pretreatment hot air-drying technique. Drying kinetics, color and phytochemical properties were examined in the study. The quality characteristics of microwave pretreatment samples caused higher losses compared to the quality characteristics of control and ultrasound samples. Marzec et al. (2020) investigated the effect of hot air and microwave-assisted hot air-drying techniques on the quality of ‘Conference’ and ‘Alexander Lucas’ variety dried pear fruits. It was determined that drying methods affected the varieties, but there was no significant difference between the varieties in terms of general quality characteristics. There are many studies on drying different varieties of pear fruits using microwave technique; Fumagalli and Silveira (2007; ‘Packham's Triumph’ pear), Li et al. (2021; ‘Balsam’ pear), Zhang et al. (2023; ‘Dangshan’ pear), Tepe & Tepe (2024; ‘Deveci’ pear), Coşkun-Topuz et al. (2022; ‘Mellaki’ pear), Kian-Pour (2023; ‘Santa Maria’ pear), Onwuzuruike et al. (2022; ‘African’ pear) etc. However, it has been seen that the number of studies on drying ‘Santa Maria’ pear fruits is still insufficient.

In this study, the drying rate - *DR*, moisture rate - *MR*, effective moisture diffusion D_{eff}, color, specific moisture absorption rate - *SMER*, specific energy consumption - *SEC*, and greenhouse gas emission - *GHG* values of *Santa Maria* variety pear fruit dried with microwave and hot air assisted microwave methods were compared.

2. Materials and Methods

2.1. Raw fruit

Fresh ‘Santa Maria’ fruits were purchased from a local market in Tokat province. The fruits were first washed with chlorinated tap water and sliced crosswise into circular slices for chips. An average of 140 g of sample was used in thermal treatments.

2.2. Drying devices

Microwave drying (MD): Fresh ‘*Santa Maria’* fruits were used in a Vestel brand and MD-GD23 model microwave oven. The microwave oven has a total output power of 900 W and its dimensions are 305 mm × 508 mm × 385 mm in height × width × depth, respectively. The products were placed on a glass plate and dried on the rotating glass tray in the oven at 360, 540, 720, and 900 W power values.

Microwave-assisted convective drying (*MACD*): Fresh fruits was dried by Ariston Hotpoint Brand MWHA 33343 model 2450 MHz (Italy). This dryer is a device with both hot air and microwave features. The AND brand GF-300 model precision balance (0.01 g) was used to follow the weight change of the samples in the drying processes.

2.3. Moisture content

Equation number 1 was used to determine the moisture content of fresh fruits on a dry basis (Yağcıoğlu, 1999).

$$N_{d.b.} = \frac{M_i - M_S}{M_S} \times 100 \qquad (1)$$

Here: Mi; Initial weight (g), Ms; Final weight (g).

2.4. Drying rate (*DR*)

Equation number 2 was used to determine the drying rates of dried fruits (Doymaz et al., 2006).

$$DR = \frac{M_{t-M(t+dt)}}{dt} \quad (2)$$

Where: M_t; Moisture content (g moisture/g drying matter), d_t; minutes, DR; Drying rate (g moisture/g drying matter minutes).

2.5. Moisture rate (*MR*)

To determine the rate of moisture removed from the dried fruits, equation number 3 was used (Maskan, 2000).

$$MR = \frac{M-M_e}{M_0-M_e} \quad (3)$$

Where: MR: Moisture content, M; Instantaneous moisture content of the product (g moisture/g dry matter), M_e; Equilibrium moisture content of the product (g moisture/g dry matter), M_o; Initial moisture content of the product (g moisture/g dry matter).

2.6. Effective moisture diffusion (D_{eff})

Equation number 4 was used to calculate the effective moisture diffusion values of dried fruits (Corzo et al., 2008).

$$\ln MR = ln\frac{8}{\pi^2} - \frac{\pi^2 \cdot D_{eff} \cdot t}{4L^2} \quad (4)$$

Where: D_{eff}: Effective diffusion value (m^2/s), L; half of the thickness value of the product (m).

2.7. Total energy consumption

A Polaxtor brand PLX-15366 model energy analyzer (± 0.02 kWh) was used to measure the energy consumption values of dried fruits.

2.8. Specific moisture absorption ratio (*SMER*)

Equation number 5 was used to calculate the specific moisture absorption ratio of dried fruits (Surendhar et al., 2019).

$$SMER = \frac{Evaporated\ moisture\ (kg)}{Consumed\ energy\ (kWh)} \quad (5)$$

Where: SMER: Specific moisture removal rate (kg/kWh).

2.9. Specific energy consumption (*SEC*)

Equation number 6 was used to calculate specific energy consumption values in dried fruits (Motevali et al., 2012).

$$SEC = \frac{P \times t \times 10^{-6}}{m_w} \quad (6)$$

Where: SEC: Specific energy consumption (kWh/kg), P: Microwave power value (W), t: Drying time, mw; amount of moisture removed (kg).

2.10. Greenhouse gas emissions (*GHG*)

The amount of GHG released into the atmosphere during drying processes was determined according to the methods of Nazari et al. (2010) and (Kaveh et al., 2021). Energy consumption values were by multiplying the specified coefficients with the consumed energy consumption values. Energy production method - Consumed energy raw material source - GHG were calculated according to the principle. Calculations were made without considering regional GHG emission differences or any other factors as variables.

2.11. Statistical analysis

SigmaPlot10 was used to create the drying kinetics of the dried samples (*p<0.05*). Duncan multiple comparison test (p<0.05) was performed in SPSS17 to statistically evaluate the findings obtained within the scope of the study.

3. Results and Discussion

3.1. Moisture rate and drying rate

The humidity and drying rate curves of the drying processes are given in Figure 1. The moisture content of the samples on a wet basis was reduced from 86% to < 7%. The decrease in the drying times of the products progressed inversely proportional to the increase in the microwave power value. The average duration of the drying processes in the microwave dryer varied between 15.5 - 54 minutes and between 34 - 36 minutes in the hybrid dryer. Alibaş et al. (2021) investigated the effects of drying methods on the drying kinetic parameters of 'Deveci' pear. The initial moisture content of the product was dried from 83.95 ± 0.01% (5.24 ± 0.003 kg moisture kg dry matter^{-1}) to a final moisture content of 11.40 ± 0.06% (0.13 ± 0.001 kg moisture kg matter^{-1}). It was dried by hot air-drying method at 60, 80, and 100 °C for 11150, 437, 252, and 148 min, respectively. Nguyen et al. (2006) studied the estimation of effective diffusion of pear tissue and cuticle by means of numerical water diffusion model. The MR was determined as a function of time in the weight loss of a pear slice at 1 °C and 20 °C and 80-90% relative humidity. Initially, it was observed that the curves decreased at 1 °C and this decrease was due to the temperature and evaporation of excess water from the free surface of the samples. Kılıç (2014) studied the determination of drying characteristics of vegetables and fruits dried under convective conditions. The decrease in the time to reach equilibrium humidity provided an increase in the dimensionless humidity ratio and drying air temperature in drying under natural convective conditions. It was observed that the moisture content of the products decreased significantly in the first 100 minutes of drying. The times to reach equilibrium humidity were 330, 250, and 210 minutes at 60, 70, and 80 °C, respectively.

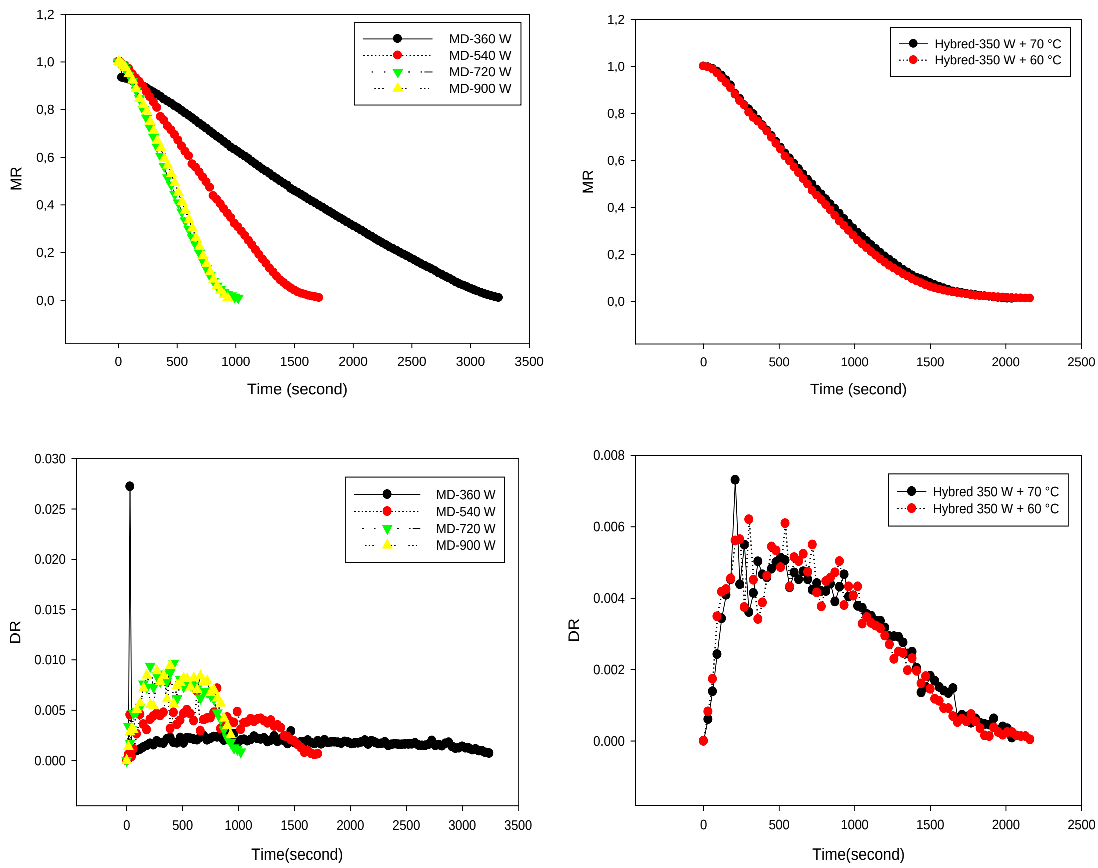

Figure 1. Drying kinetics.

3.2. Effective moisture diffusion

The effective moisture diffusion of the drying processes was affected by the microwave and hybrid power values (Table 1). The effective moisture diffusion values in the microwave dryer varied between 9.13×10^{-9} - 1.01×10^{-8} m^2/s and in the hybrid dryer between 5.58 - 5.58×10^{-9} in drying processes. The highest effective moisture diffusion value was determined as 1.01×10^{-8} m^2/s in the microwave dryer. This situation is thought to be the result of energy produced by the microwave system directly affecting the heat conversion within the product. Doymaz and Aktaş (2018) observed that the effective moisture diffusion value was positively affected by increasing the drying temperature. The reason for this was that the increase in the drying rate in the product affected the easier evaporation of moisture. Nguyen et al. (2006) worked on the estimation of the effective diffusion of pear tissue and cuticle by means of a numerical water diffusion model. Diffusion coefficient values were greater in late collected pear samples (inner cortex: 123.0 ± 48.0). This is because pears picked late are riper than those picked early. Since cell membrane deterioration is seen in products picked late, diffusion coefficients increase. Silva et al. (2016) studied three-stage intermittent drying of pears considering shrinkage and variable diffusion coefficient. In the results of the study, considering the amount of shrinkage in the samples, diffusion coefficients varying between 2.5×10^{-9} m^2/s and 6.0×10^{-11} m^2/s at 40 °C and 2.4×10^{-9} m^2/s and 1.9×10^{-10} m^2/s at 50 °C were observed. In the drying performed at 50 °C, a 28.7% decrease in the total time was obtained. This result determined that air temperature had a greater effect on drying kinetics than air flow rate. Effective moisture diffusion values of drying processes are given in Table 1.

3.3. Energy consumption values

The energy consumption curves of the drying processes are given in Figure 2.

Table 1. Effective moisture diffusion values of drying processes.

Microwave power	Effective diffusion (m^2/s)	R^2
360 W	2.54×10^{-9}	0.8407
540 W	5.83×10^{-9}	0.8637
720 W	1.01×10^{-8}	0.8766
900 W	9.13×10^{-9}	0.8012
350 W + 60 ºC	5.58×10^{-9}	0.9470
360 W + 70 ºC	5.58×10^{-9}	0.9691

It was observed that the average *SMER* values of *MD* drying processes varied between 0.006917-0.002803 kg/kWh and *SEC* values varied between 356.8205-144.5714 kWh/kg. It was observed that the average *SMER* values of hybrid drying processes varied between 0.0037-0.0016 kg/kWh and *SEC* values varied between 6261.5-2693.6 kWh/kg. Alibaş et al. (2021) investigated the effects of drying methods on the drying kinetics parameters of 'Deveci' pear. In the study, it was determined that the method with the highest total energy consumption in the hot air-drying method was 60°C. The increase in drying temperature was the determining factor in the increase in total energy consumption and the decrease in specific energy consumption. Kaveh et al. (2023) investigated the comparative evaluation of GHG emissions and specific energy consumption of different drying techniques in pear slices. For CV, IR, and MW the highest *SEC* values were obtained with the values of 267.61, 204.64, and 87.03 MJ/kg for 6 mm thickness at 50 °C, 500 W, and 270 W, respectively, while the lowest *SEC* values were 94.54, 85.36, and 28.33 MJ/kg for a 2 mm sample thickness at 70 °C, 1000 W, and 630 W, respectively. In the study, it was obtained that the *SEC* value decreased with increasing temperature-power and decreasing sample thickness. It was determined that the shrinkage values were higher at low sample thicknesses and temperature powers.

3.4. Greenhouse gas emission (*GHG*)

The *GHG* values in drying processes are given in Table 2.

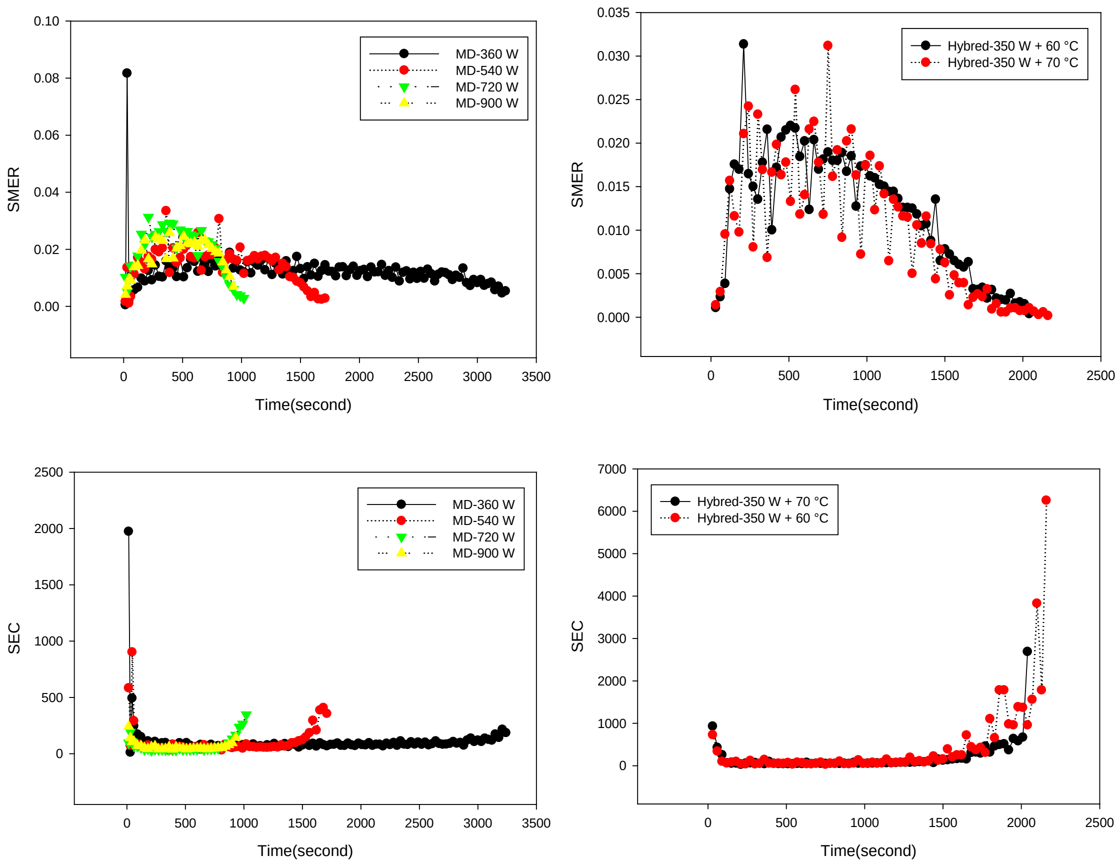

Figure 2. *SMER* and *SEC* curves of drying processes.

Table 2. GHG values.

Microwave power	Energy production methods	Fuel	*NO_x (g)*	*SO_2 (g)*	*CO_2 (g)*
360 W	Steam	Natural gas	1.32717	0	313.548
		Kerosene	1.24236	7.53304	505.325
	Gas turbine	Natural gas	0.94163	0	385.526
		Kerosene	2.85447	1.89312	516.664
	Combined cycle	Natural gas	1.45435	0	221.85
		Kerosene	1.86354	1.14376	306.646
540 W	Steam	Natural gas	1.11097	0	262.668
		Oil	1.04076	6.31064	423.325
	Gas turbine	Natural gas	0.78883	0	322.966
		Kerosene	2.39127	1.58592	432.824
	Combined cycle	Natural gas	1.21835	0	185.85
		Kerosene	1.56114	0.95816	256.886
720 W	Steam	Natural gas	0.84197	0	199.068
		Oil	0.78876	4.78264	320.825
	Gas turbine	Natural gas	0.59783	0	244.766
		Kerosene	1.81227	1.20192	328.024
	Combined cycle	Natural gas	0.92335	0	140.85
		Kerosene	1.18314	0.72616	194.686
900 W	Steam	Natural gas	0.8877	0	209.88
		Oil	0.8316	5.0424	338.25
	Gas turbine	Natural gas	0.6303	0	258.06
		Kerosene	1.9107	1.2672	345.84
	Combined cycle	Natural gas	0.9735	0	148.5
		Kerosene	1.2474	0.7656	205.26
350 W + 60 ºC	Steam	Natural gas	1.41225	0	333.9
		Oil	1.323	8.022	538.125
	Gas turbine	Natural gas	1.00275	0	410.55
		Kerosene	3.03975	2.016	550.2
	Combined cycle	Natural gas	1.54875	0	236.25
		Kerosene	1.9845	1.218	326.55
350 W + 70 ºC	Steam	Natural gas	1.77809	0	420.396
		Oil	1.66572	10.10008	677.525
	Gas turbine	Natural gas	1.26251	0	516.902
		Kerosene	3.82719	2.53824	692.728
	Combined cycle	Natural gas	1.94995	0	297.45
		Kerosene	2.49858	1.53352	411.142

** The value of 0 (Zero) indicates that the SO2 gas released into the atmosphere during energy production using natural gas fuel with steam, gas turbine and combined cycle methods is not at a significant level.

Çeşmeli and Pençe (2020) reported that GHG emissions exceed the capacity of our world to renew itself, leading to serious consequences such as ozone layer depletion, global warming and the decrease in food resources. In addition, GHG are one of the biggest factors in the formation of the ecological footprint. For the world to be more livable and sustainable, biomass areas and the ecological footprint must be kept in balance. To achieve this balance, the future status of greenhouse gas emissions must be predicted accurately. According to Table 2, it was determined that the *GHG* values decreased with the increase in microwave power values. This is because the drying time of the product decreased at high microwave power values, and the amount of energy consumed by the dryer also decreased. This caused the GHG values to decrease. Kaveh et al. (2023) investigated the comparative evaluation of GHG emissions and specific energy consumption of different drying techniques in pear slices. As seen in the microwave drying process, the highest CO_2 levels were recorded in SP-HO (89.21 kg/kg water) and GT-GO (91.21 kg/kg water) plants drying at 270 W with a sample thickness of 6 mm. The lowest CO_2 level was 12.75 kg/kg water in CC-NG plant with 630 W power and 2 mm sample thickness. The highest NO_x emissions (0.50 kg/kg water) were found in the GT-GO plant with 270 W and 6 mm thickness. The lowest NO_x (0.05 kg/kg water) was in the GT-NG plant with 2 mm sample thickness and drying at 630 W. In addition, increases in MW power led to a decrease in CO_2 and NO_x emissions, while an increase in sample thickness led to an increase in CO_2 and NO_x emissions. This high MW power required less energy to remove moisture from pear samples, which resulted in a decrease in greenhouse gas emissions. Kaveh et al. (2021) conducted a green pea drying study. In this study, they determined the highest and lowest CO_2 greenhouse gas emission values as 225.80 and 29.70 g/kg moisture.

The values in literature are higher than the values in this study. The reason for this is that the drying processes were carried out in industrial type convective dryers. Motevali and Koloor (2017) investigated the *GHG* values of different drying systems. They found the lowest CO_2 and NO_x greenhouse gas emissions in the microwave dryer as 38.55 g and 1.54 g. In this study, it was seen that the *GHG* values obtained with the microwave dryer were compatible with the GHG values obtained with the microwave dryer in the literature.

4. Conclusion

It was observed that microwave power values affected the drying kinetics, energy consumption and *GHG* values of pear chips. With the increase in power values, the moisture content of the samples also increased. NO_x gas emission was determined as 2.85 g at the highest power value of 360 W. SO_2 gas emission was determined as 6.31 g at the highest power value of 360 W. CO_2 gas emission was determined as 516.66 g at the highest power value of 360 W. The drying processes of the samples were affected by effective moisture diffusion, microwave and hybrid power values. In the pear chip study, it is thought that the energy produced by the microwave system directly affects the heat conversion within the product. The highest *SMER* and lowest *SEC* values were determined in the drying processes performed in the microwave dryer at 900 W power value and in the hybrid dryer at 350 W – 60 ºC.

Conflict of interest

The authors declare no conflicts of interest.

Authorship contribution statement

M.T: Planning, data processing, article writing, editing.
S.A: Laboratory work, data processing.

References

Aghbashlo, M., Kianmehr, M.H., & Samimi-Akhijahani, H. (2008). Influence of drying conditions on the effective moisture diffusivity, energy of activation and energy consumption during the thin-layer drying of berberis fruit (*Berberidaceae*). *Energy Conversion and Management*, 49(10), 2865-2871. https://doi.org/10.1016/j.enconman.2008.03.009.

Afzal, T. M., Abe, T., & Hikida, Y. (1999). Energy and quality aspects during combined FIR-convection drying of barley. *Journal of Food Engineering*, 42, 177-182. https://doi.org/10.1016/S0260-8774(99)00117-X.

Aktaş, M., Şevik, S., Amini, A., & Khanlari, A. (2016). Analysis of drying of melon in a solar-heat recovery assisted infrared dryer. *Solar Energy*, 137: 500-515. https://doi.org/10.1016/j.solener.2016.08.036.

Alibas, I., Yılmaz, A., Günaydın, S., & Arkain, B. (2021). Kurutma yöntemlerinin deveci armudunun kurutma kinetiği ve renk parametreleri üzerine etkisi. *Turkish Journal of Agriculture-Food Science and Technology*, *9*(5), 897-908.

Antonio, G. C., Alves, D. G., Azoubel, P. M., Murr, F. E. X., & Park, K. J. (2008). Influence of osmotic dehydration and high temperature short time processes on dried sweet potato (*Ipomoea batatas* Lam.). *Journal of Food Engineering*, 84, 375-382. https://doi.org/10.1016/j.jfoodeng.2007.05.033.

Asokapandian, S., Venkatachalam, S., Swamy, G. J., & Kuppusamy, K. (2015). Optimization of foaming properties and foam mat drying of muskmelon using soy protein. *Journal of Food Process Engineering*, 39(6): 692-701. https://doi.org/10.1111/jfpe.12261.

Bonazzi, C., & Dumoulin, E. (2011). Quality changes in food materials as ınfluenced by drying processes. https://doi.org/10.1002/9783527631667.ch1.

Calín-Sánchez, A., Lipan, L., Cano-Lamadrid, M., Kharaghani, A., Masztalerz, K., Carbonell-Barrachina, Á. A., & Figiel A. (2020). Comparison of traditional and novel drying techniques and its effect on quality of fruits, vegetables and aromatic herbs, *Foods* 9(9): 1–27. https://doi.org/10.3390/foods9091261, 32916839.

Chojnacka, K., Mikula, K., Izydorczyk, G., Skrzypczak, D., Witek-Krowiak, A., Moustakas, K., Ludwig, W., & Kułażyński, M. (2021). Improvements in drying technologies - Efficient solutions for cleaner production with higher energy efficiency and reduced emission, *Journal of Cleaner Production*, 320: 128706. https://doi.org/10.1016/j.jclepro.2021.128706.

Coşkun-Topuz, F., Bakkalbaşı, E., Aldemir, A., & Javidipour, I. (2022). Drying kinetics and quality properties of Mellaki (*Pyrus communis* L.) pear slices dried in a novel vacuum-combined infrared oven. *Journal of Food Processing and Preservation*, 46(10). https://doi.org/10.1111/jfpp.16866.

Çeşmeli, M. Ş., & Pençe, İ. (2020). Makine Öğrenimi Yöntemleri ile Türkiye için Sera Gazı Emisyonu Tahmini. *Academic Platform-Journal of Engineering and Science*, *8*(2), 332-348.

Dias, P. G. I., Sajiwanie, J. W. A., & Rathnayaka, R. M. U. S. K. (2020). Chemical composition, physicochemical and technological properties of selected fruit peels as a potential food source. *International Journal of Fruit Science*, 20(2): 240-251. https://doi.org/10.1080/15538362.2020.1717402.

Doymaz, İ., & Aktaş, C. (2018). Determination of drying and rehydration characteristics of eggplant slices. *Journal of the Faculty of Engineering and Architecture of Gazi University*, *33*(3).

Falade, K. O., Igbeka, J. C., & Ayanwuyi, F. A. (2007). Kinetics of mass transfer, and colour changes during osmotic dehydration of watermelon. *Journal of Food Engineering*, 80(3), 979-985.

FAO (2011). Energy-smart food for people and climate. 2/3/2017.

Fumagalli, F., & Silveria, A. M. (2007). Quality evaluation of microwave-dried Packham's Triumph pear. *Drying Technology*, 23(9-11), 2215-2226. https://doi.org/10.1080/07373930500212701.

Guan, L., Xu, H., Jiang, M., Su, D., Guo, Y., Chen, X., Wang, D., & Song, H. (2024). Effects of penetrating microwave hot-air rolling blanching pretreatment for the drying of hawthorn slices: Evaluation of enzyme activity, drying characteristics, moisture migration, microstructure, and quality attributes. *Food and Bioprocess Technology*. https://doi.org/10.1007/s11947-024-03525-7.

Haryanto, B., Hasibuan, R., Lubis, A. H., Wangi, Y., Khosman, H., & Sinaga A. W. (2020). Drying rate of turmeric herbal (Curcuma longa L.) using tray dryer. Journal of Physics: Conference Series, https://doi.org/10.1088/1742-6596/1542/1/012056.

Hexa Research (2018). Global fruit powder market size and forecast, by product (speciality fruits, conventional fruits), by application (food & beverages, pharmaceutical, nutraceutical, others), and trend analysis, 2015 - 2025. In Market Research Report - Food & Beverages, (pp. 59).

Juhaimi, F. A., Uslu, N., Özcan, M. M., & Babiker, E. F. E. (2016). Effect of drying on antioxidant activity, total phenol and mineral contents of pear fruits. *Journal of Food Safety and Food Quality*, 67(2016): 113-148. https://doi.org/10.2376/0003-925X-67-164.

Junqueira, J., Corrêa, J., & Ernesto D. (2017). Microwave, convective, and intermittent microwave-convective drying of pulsed vacuum osmodehydrated pumpkin slices. *Journal of Food Processing and Preservation*, 41(6): e13250. https://doi.org/10.1111/jfpp.13250.

Kaveh, M., Abbaspour-Gilandeh, Y., & Nowacka, M. (2021). Comparison of different drying techniques and their carbon emissions in green peas. *Chemical Engineering and Processing-Process Intensification*, *160*, 108274.

Kaveh, M., Çetin, N., Gilandeh, Y. A., Sharifian, F., & Szymanek, M. (2023). Comparative evaluation of greenhouse gas emissions and specific energy consumption of different drying techniques in pear slices. *European Food Research and Technology*, *249*(12), 3027-3041.

Khachik, F., Beecher, G. R., Goli, M. B., & Lusby, W. R. (1991). Separation, identification, and quantification of carotenoids in fruits, vegetables and human plasma by high performance liquid chromatography. *Pure Appl. Chem*. 63, 71–80.

Khampakool, A., Soisungwan, S., & Park, S. H. (2019). Potential application of infrared assisted freeze drying (IRAFD) for banana snacks: Drying kinetics, energy consumption, and texture. *LWT*, 99, 355-363. https://doi.org/10.1016/j.lwt.2018.09.081.

Kiliç, E. E. (2014). *Konvektif koşullarda kurutulan sebze ve meyvelerin kuruma karakteristiklerinin belirlenmesi* (Master's thesis, Fen Bilimleri Enstitüsü).

Kutlu, N., İşci, A., & Demirkol, Ö. Ş. (2015). Thin layer drying models in food systems. GIDA *Jornal of Food* 40(1): 39-46. https://doi.org/10.15237/gida.GD14031.

Laur, L. M., & Tian, L. (2011). Provitamin A and vitamin C contents in selected California-grown cantaloupe and honeydew melons and imported melons. J. Food Compost. Anal. 24, 194–201.

Li, T. S., Sulaiman, R., Rukayadi, Y., & Ramli, S. (2021). Effect of gum Arabic concentrations on foam properties, drying kinetics and physicochemical properties of foam mat drying of cantaloupe. *Food Hydrocolloids*, 116. https://doi.org/10.1016/j.foodhyd.2020.106492.

Li, J., Li, Z., Li, L., Song, C., Raghavan, G. S. V., & He, F. (2021). Microwave drying of balsam pear with online aroma detection and control. *Journal of Food Engineering*, 288: 110139. https://doi.org/10.1016/j.jfoodeng.2020.110139.

Li, B., Fan, X., Yu, S., Xia, H., Nong, Y., Bian, J., Sun, M., & Zi, W. (2023). Microwave heating of biomass waste residues for sustainable bioenergy and biomass materials preparation: A parametric simulation study. Energy, 274. https://doi.org/10.1016/j.energy.2023.127347.

Majid, I., & Nanda, V. (2017). Effect of sprouting on the physical properties, morphology and flowability of onion powder. *Journal of Food Measurement and Characterization*, 11(4), 2033–2042. https://doi.org/10.1007/s11694-017-9586-2.

Marzec, A., Kowalska, H., Kowalska, J., Domian, E., & Lenart, A. (2020). Influence of pear variety and drying methods on the quality of dried fruit. *Molecules*, 25(21): 5146. https://doi.org/10.3390/molecules25215146.

Moradi, M., Azizi, S., Niakousari, M., Kamgar, S., & Khaneghah, A. M. (2020). Drying of green bell pepper slices using an IR-assisted Spouted Bed Dryer: An assessment of drying kinetics and energy consumption. *Innovative Food Science & Emerging Technologies*, 60. https://doi.org/10.1016/j.ifset.2019.102280.

Morais, R. M. S. C., Morais, A. M. M. B., Dammak, I., Bonilla, J., Sobral, P. J. A., Laguerre, J. C., Afonso, M. J., & Ramalhosa, E. C. D. (2018). Functional Dehydrated Foods for Health Preservation. *Journal of Food Quality*, https://doi.org/10.1155/2018/1739636.

Moses, J. A., & Authority, F. D. (2014). Novel drying techniques for the food industry, Food Engineering Reviews. (2014) 6, no. 3, 43–55, https://doi.org/10.1007/s12393-014-9078-7, 2-s2.0-84905190068.

Motevali, A., & Kloor, R.T. (2017). A comparison between pollutants and greenhouse gas emissions from operation of different dryers based on energy consumption of power plants. *Journal of Cleaner Production*, 154, 445-461.

Mouhoubi, K., Boulekbache-Makhlouf, L., Mehaba, W., Himed-Idir, H., & Madani, K. (2021). Convective and microwave drying of coriander leaves: Kinetics characteristics and modeling, phenolic contents, antioxidant activity, and principal component analysis. *Journal of Food Process Engineering*, https://doi.org/10.1111/jfpe.13932.

Nguyen, T. A., Verboven, P., Scheerlinck, N., Vandewalle, S., & Nicolaï, B. M. (2006). Estimation of effective diffusivity of pear tissue and cuticle by means of a numerical water diffusion model. *Journal of Food Engineering*, *72*(1), 63-72.

Nizamloğlu, N. M. (2022). Farklı sıcaklık ve mikrodalga güçlerinde kurutulan elma dilimlerinin kurutma özellikleri. *Akademik Gıda*, 20(3), 253-262. https://doi.org/10.24323/akademik-gida.1186984.

Onwuzuruike, U. A., Iguh, B., Uzochukwu, U. C., & Ezuma, V. (2022). Effect of different drying method on the quality characteristics of african pear (*Dacroydes edulis*) mesocarp flour. *Nigeria Agricultural Journal*, 53(1), 91-102.

Önal, B., Adiletta, G., Matteo, M. D., Russo, P., Ramos, I. N., & Silva, C. L. M. (2021). Microwave and ultrasound pre-treatments for drying of the "rocha" pear: ımpact on phytochemical parameters, color changes and drying kinetics. *Foods*, 10(4), 53. https://doi.org/10.3390/foods10040853.

Özbek, H. N. (2021). Radio frequency-assisted hot air drying of carrots for the production of carrot powder: Kinetics and product quality. *LWT*, 152, https://doi.org/10.1016/j.lwt.2021.112332.

Salahi, M. R., Mohebbi, M., & Taghizadeh, M. (2014). Foam-mat drying of cantaloupe (*Cucumis melo*): optimization of foaming parameters and ınvestigating drying characteristics. *Journal of Food Processing and Preservation*, 39(6), 1798-1808.

Shen, L., Zhu, Y., Liu, C., Wang, L., Liu, H., Kamruzzaman, M., Liu, C., Zhang, Y., & Zheng, X. (2020). Modelling of moving drying process and analysis of drying characteristics for germinated brown rice under continuous microwave drying. *Biosystems Engineering*, 195, 64-88. https://doi.org/10.1016/j.biosystemseng.2020.05.002.

Silva, V., Costa, J. J, Figueiredo, A. R., Nunes, J., Nunes, C., Ribeiro, T.I., & Pereira, B. (2016). Büzülme ve değişken difüzyon katsayısı dikkate alınarak armutların üç aşamalı aralıklı kurutulması üzerine çalışma. *Gıda Mühendisliği Dergisi* , *180* , 77-86.

Sutar, P. P., & Prasad, S. (2008). Microwave Drying Technology-Recent Developments and R&D Needs in India. In proceedings of 42nd ISAE Annual Convention, during February 1-3.

Tepe, T. K., & Tepe, F. B. (2024). Improvement of pear slices drying by pretreatments and microwave-assisted convective drying method: drying characteristics, modeling of artificial neural network, principal component analysis of quality parameters. *Journal of Thermal Analysis and Calorimetry*, 149, 7313-7328. https://doi.org/10.1007/s10973-024-13280-8.

Tunçkal, C., Ozkan-Karabacak, A., Tamer, C. E., Yolcı-Omeroglu, P., & Goksel, Z. (2022). Mathematical modelling and optimization of melon slice drying with response surface methodology in a heat pump drying system. *Latin American Applied Research*, 52(2), 101-110.

Turkiewicz, I. P., Wojdylo, A., Tkacz, K., Lech, K., Michalska-Ciechanowska, A., & Nowicka, P. (2020). The influence of different carrier agents and drying techniques on physical and chemical characterization of Japanese quince (Chaenomeles japonica) microencapsulation powder. *Food Chemistry*, 323, https://doi.org/10.1016/j.foodchem.2020.126830.

Wu, X. F., Zhang, M., & Bhandaria, B. (2019). A novel infrared freeze drying (IRFD) technology to lower the energy consumption and keep the quality of Cordyceps militaris. *Innovative Food Science & Emerging Technologies*, 54, 34-42. https://doi.org/10.1016/j.ifset.2019.03.003.

Yano, M., Kato, M., Ikoma, Y., Kawasaki, A., Fukazawa, Y., Sugiura, M., Matsumoto, H., Oohara, Y., Nagao, A., & Ogawa, K. (2005). Quantitation of carotenoids in raw and processed fruits in Japan. *Food Sci. Technol. Res.* 11, 13-18.

Zhang, H., Zheng, W., Yan, L., Liu, W., Yao, F., Liu, C., & Zheng, L. (2023). Effects of vacuum microwave combined with freeze-drying on the physicochemical properties, phenolic compounds, and antioxidant capacity of pear fruit slices. *Journal of Food Science,* 88(7): 2807-2820. https://doi.org/10.1111/1750-3841.16653.

Zia, S., Khan, M. R., & Aadil, R. M. (2023). Kinetic modeling of different drying techniques and their influence on color, bioactive compounds, antioxidant indices and phenolic profile of watermelon rind. *Journal of Food Measurement and Characterization*, 17, 1068–1081.

Zielinska, M., Ropelewska, E., Xiao, H. W., Mujumdar, A. S., & Law, C. L. (2020). Review of recent applications and research progress in hybrid and combined microwave-assisted drying of food products: Quality properties. Critical Reviews in *Food Science and Nutrition*, 60(13), 2212-2264. https://doi.org/10.1080/10408398.2019.1632788.