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İÇİNDEKİLER

BÖLÜM 1

THE EFFECT OF DIFFERENT PLANT DENSITIES ON ORGANIC CUCUMBER CULTIVATION IN GREENHOUSE[1]

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Introduction

Greenhouse vegetable production is of great importance for growing crops throughout the year, both in terms of meeting national vegetable needs and gaining a foothold in foreign markets. In recent years, with the increase in population and the emergence of food

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shortages, the need to make food sources sustainable has become an important issue.

The cucumber plant is one of the three main vegetables widely grown in greenhouses worldwide and is a plant of great economic value in agricultural production (Han et al., 2012). Among the vegetables grown in our country, cucumber ranks among the top in terms of production value, with approximately 1.9 million tons produced on 35.278 hectares in 2023. World production in the same year was reported to be approximately 98 million tons (FAO, 2023).

Limitations in water and soil resources in open-field vegetable production, limited control of climatic and biological factors, may mean that protected cultivation could be an alternative for the production of some foods. The production unit, the area planted, is a factor in determining the optimal use of inputs (Khoram and Mohamady, 2021). For these reasons, protected vegetable cultivation has gained great importance in recent years. Furthermore, cucumber yields under protected cultivation conditions can be increased many times over compared to open field cultivation (Singh et al., 2017). The main problems encountered in organic vegetable cultivation are the difficulties in controlling weeds and managing diseases and pests. For this reason, protective measures in greenhouse cultivation must be well planned from the seed sowing period to harvest. Factors such as environmental conditions, structural characteristics of greenhouses, greenhouse cover type, location and orientation of greenhouses, shading and characteristics of shading materials, cultivation sites, mulching, and the use of proper irrigation systems must be taken into account (Özer, 2012; Özer and Uzun, 2013; Uzun et al., 2013). In greenhouse cucumber cultivation, plant density is one of the critical agricultural factors that determine both the quantity and quality of the product (Ayala-Tafoya et al., 2019). Plant density is defined as the number of plants per unit area and is directly related to productivity.

Increasing plant density generally increases total yield per unit area (Peil and Gálvez, 2004; Mendoza-Pérez et al., 2018; Ayala-Tafoya et al., 2019). One study observed that increasing density from 2.24 to 4.48 plants m^{-2} increased product yield by 69% (Parks et al., 2019). However, while increasing plant density has a positive effect on the total amount of product obtained per unit area, individual leaf health and fruit quality are generally optimized at lower densities.

In both protected and open-field vegetable cultivation, cultural practices are as important as environmental factors. In this context, when planning production, planting systems and spacing must be carefully reviewed, taking into account potential problems caused by weeds and moisture. In greenhouse cultivation, the occurrence of fungal and bacterial diseases in cucumber plants, depending on the relative humidity inside the greenhouse and whether the light used during the growth and development periods of the plants is sufficient, causes a significant decrease in yield and quality (Zhu et al., 2016; Sun et al., 2021).

Throughout the plant cultivation period, fungal diseases caused by high humidity and the increased presence of microorganisms causing diseases in the greenhouse negatively affect plant growth and development, leading to a decrease in yield. It is possible to prevent humidity in the greenhouse from negatively affecting cultivation by adjusting planting distances. Studies have shown that under conditions of low plant density, an increase in light intercepted by plant leaves leads to an increase in fruit number and yield (Verheul, 2012).

The study aimed to investigate the effects of different planting systems and planting distances used in organic cucumber cultivation in greenhouses on certain leaf characteristics and yield values, thereby determining the appropriate planting systems and plant density for practical application.

Material and Methods

The study was conducted in two greenhouses belonging to the Faculty of Agriculture at Ondokuz Mayıs University. The greenhouses where the research was carried out were 6 m wide, 20 m long (120 m²), and 3 m high. They were covered with PE plastic film (containing AF: antifog, AV: antivirus, IR: infrared, and UV: ultraviolet additives) and featured a semi-arch roof design with continuous ridge ventilation (Figure 1).

Figure 1 A view of the greenhouse where the research was conducted

Raised beds (ridges) were utilized as planting sites, with four beds, each 1 m wide and 18 m long, established in each greenhouse. After installing drip irrigation pipes, the planting sites were prepared by covering the beds with a mulch material that was 1.30 m wide, 0.03 mm thick, black on the underside, and silver on the upper surface. The 'Sinbad F1' variety, which is suitable for regional cultivation, early maturing, and ideal for spring greenhouse production, was used as the plant material. This variety is a parthenocarpic cultivar characterized by high fruit quality, firmness, suitability for storage and transport, high yield, and regular fruit set.

Methods

The research was conducted as early-season cucumber cultivation in accordance with organic farming procedures and regulations.

Seeds were sown in 28-cell plug trays with cell dimensions of 7 x 7 cm. A seedling growth medium consisting of a mixture of soil and farmyard manure (1:2 ratio) was used as the substrate. Seedlings were grown in plug trays in a glass greenhouse until the time of transplanting (the four true-leaf stage).

Following the preparation of the soil, 80 liters of farmyard manure consisting of well-rotted cow and sheep manure—and Biofarm commercial organic fertilizer (at a rate of 250 kg da^{-1}) were incorporated into the raised beds. Irrigation was monitored daily and performed during the early morning and the cool hours of the evening. For fertilization, compost tea (Biofarm) was applied weekly at a rate of 0.25 ml solution per plant. Pruning and monitoring for pests and diseases were conducted daily throughout the growing period.

Planting Systems and Planting Densities

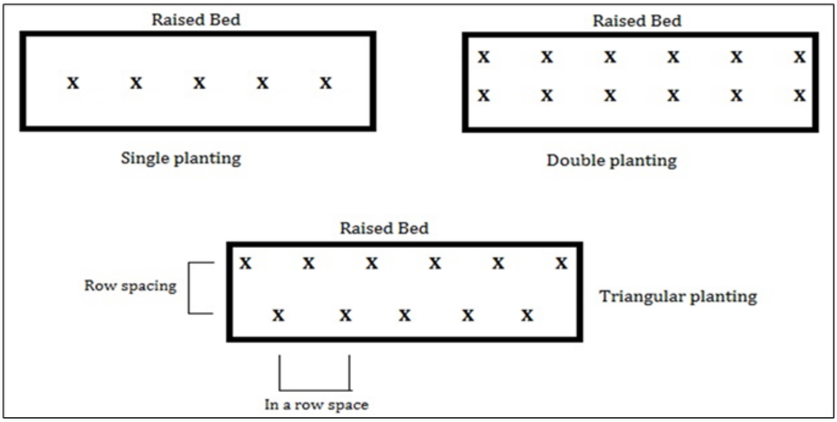
In the study, cucumber transplanting was carried out according to the planned planting systems: single-row, double-row, and triangular planting. Three different plant densities were used for the double-row and triangular planting treatments, while two different plant densities were applied for the single-row planting treatment (Table 1).

Table 1 Planting systems, planting spacings and plant densities

Planting system	Between row (cm)		In a row (cm)	Plant Density (plant m^{-2})	Treatment
	Wide row	Row spacing			
Double row*	110	40	50	2.67	D3
Single row	150	-	40	1.67	S1
Triangular row	110	40	80	1.93	T3
Triangular row	110	40	65	2.37	T2
Triangular row	110	40	50	3.09	T1
Double row	110	40	65	2.38	D1
Double row	110	40	80	2.05	D2
Single row	150	-	60	1.11	S2
*Control					

For the control treatment, double-row planting a method widely preferred in greenhouse tomato cultivation was selected, with row spacing and in a row spacings of 40x50 cm. Once the cucumber seedlings reached the four-leaf stage, they were transplanted in accordance with eight different planting patterns (Figure 1).

Figure 1 The appearance of the planting systems used in the research



Traits Examined in the Research

In the cucumber plants examined in the research, measurements were taken at 20 day intervals starting from planting. Leaf chlorophyll content was determined as the chlorophyll concentration index (cci) in the leaves using a chlorophyll meter (CCM-200, Opti-Sciences, USA) in the early morning hours on old, medium, and young leaves of the cucumber plants. Stomatal conductance was measured as mmol $m^{-2}s^{-1}$ between 09:00-11:00 in the morning using a porometer (SC-1, Decagon Devices, USA) on young, medium, and old leaves of the cucumber plants. Leaf area was determined using a leaf area estimation model (Uzçelik-I) through linear measurements on young and old leaves of the cucumber plant.

The estimated leaf area was determined with the help of the relevant formula by measuring the leaf blade length (LL) and the distance between the two widest points of the leaf blade (W) on the plant leaves (Uzun and Çelik, 1998).

$$YA=-114,43-7,31*LL/W*PS+0,651*W^2+210,86*LL/W$$

Yield per plant and total yield values were calculated as yield values. The total yield values of cucumber fruits harvested from the first harvest to the last harvest date were divided by the number of plants to determine the yield per plant value in kg. The total yield value was obtained by calculating the equivalent per decare of the value obtained from harvests made throughout all harvest periods.

Statistical Analysis

The research was established according to a split-plot experimental design with 3 replications and 6 plants in each replication. Microsoft Excel program was used to create graphs based on the data obtained from the study, and SPSS (IBM, version 17.0, USA) statistical analysis program was used for data evaluation. The differences between the means obtained from the applications were determined by Duncan's multiple comparison test.

Results and Discussion

The means according to the planting densities determined by different planting systems and planting pattern applications examined in the study, and the grouping based on the differences between the means are given in Table 2.

Table 2 The effects of different plant densities on chlorophyll content, leaf stomatal conductance, average leaf area, yield per plant, and total yield in cucumber plants

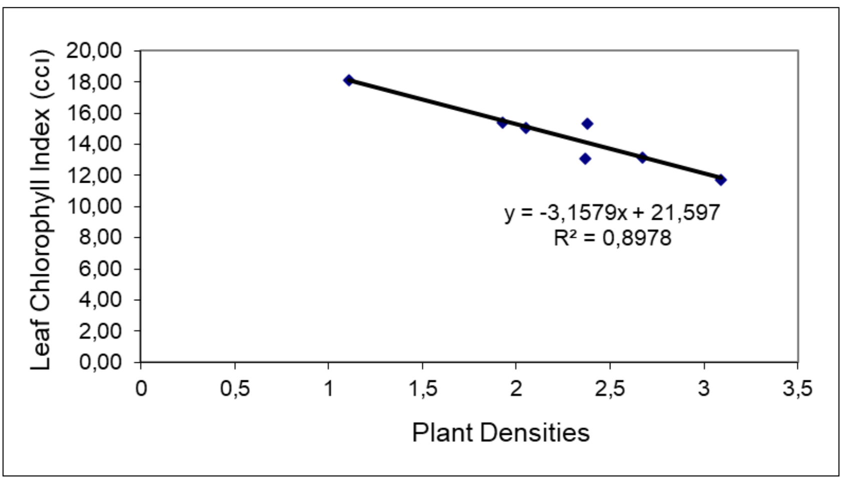
Treatment	LCI (SPAD)	LSC (mmol $m^{-2}s^{-1}$)	TLA (cm^2)	YPP (kg)	TY (ton da^{-1})
D3*	13.1 c	3.17 b	126.93 d	3.34 d	8.91 c
S1	18.6 a	5.81 a	145.59 c	5.32 b	8.86 c
T3	15.4 b	0.64 e	152.73 b	5.59 a	10.76 a
T2	13.1 c	3.99 b	153.93 b	3.64 d	8.62 c
T1	11.7 d	2.39 c	216.60 a	2.50 e	7.71 d
D1	15.3 b	2.14 d	107.64 e	4.04 c	9.61 b
D2	15.0 b	2.28 c	141.33 c	4.32 c	8.85 c
S2	18.1 a	2.14 d	111.53 e	5.38 ab	5.98 e

$p<0.05$, *Control, LCI: Leaf chlorophyll index, LSC: Leaf stomatal conductance, TLA: Total leaf area, YPP: Yield per plant, TY: Total yield

Leaf Chlorophyll Index (SPAD)

The highest leaf chlorophyll content (18.6 cci) in the cucumber leaves examined in the research was calculated in the S1 application. The lowest leaf chlorophyll content (11.7) was calculated in the leaves of cucumber plants in the T1 application. As plant density increased in cucumber, leaf chlorophyll content showed a linear decrease. The degree of relationship (r^2) between plant density and leaf chlorophyll content was 0.89 (Graph 1).

Graph 1 The relationship between plant density and cucumber leaf chlorophyll content



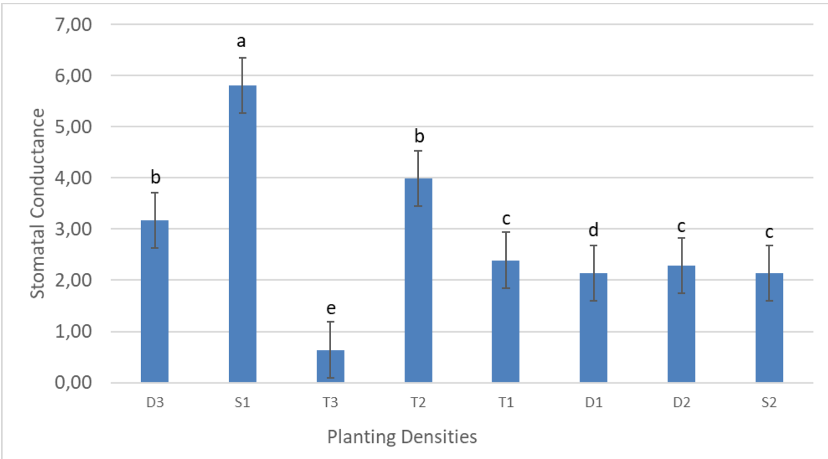
In organic cucumber cultivation in greenhouses, the relationship between plant density and leaf chlorophyll content aligns with some findings in the literature while showing nuanced differences with others. A study on soybeans indicated that as plant density increases, the leaf chlorophyll (greenness) index tends to decrease due to population pressure and interplant light competition (Moreira et al., 2015).

The reduction of photosynthetically active radiation (PAR) reaching the lower leaves in high-density canopies can negatively affect chlorophyll synthesis or persistence (Ribas et al., 2020; Pao et al., 2021). In low-density (2.25 plants m^{-2}) applications, better light penetration into the middle and lower parts of the canopy is reported to increase chlorophyll content (Pao et al., 2021; Ding et al., 2022). The plant density (1.67 plants m^{-2}) at which the highest leaf chlorophyll content was obtained in our study is consistent with the findings of Tafoya et al. (2019), who determined the highest SPAD value at a plant density of 1.68 plants m^{-2}. In conclusion, our finding that chlorophyll content decreases as plant density increases was found to be completely consistent with the statement in scientific studies that increasing plant density leads to increased light competition and decreased individual plant performance (dry weight, chlorophyll, etc.) (Diaz et al., 1999; Ayala-Tafoya et al., 2019).

Leaf Stomatal Conductance

The effect of different plant densities on stomatal conductance (mmol $m^{-2}s^{-1}$) in cucumber leaves is given in Graph 2. While the highest leaf stomatal conductance (5.8 mmol/m^2s^{-1}) in cucumber leaves was observed in the S1 application, the lowest leaf stomatal conductance (0.6 mmol $m^{-2}s^{-1}$) was recorded in the leaves of cucumber plants in the T3 application. Stomatal conductance is directly affected by microclimatic factors such as light, temperature, and CO_2 concentration (Grantz and Zeiger, 1986). Additionally, high light intensity generally increases stomatal conductance (Bakker et al., 1991). Sparser plant placement provides better airflow within the canopy (Ortiz et al., 2009). Previous studies indicate that high air exchange rates and appropriate moisture balance help maintain stomatal conductance; otherwise, stomata begin to close to prevent water stress (Choudhury and Monteith, 1986).

Graph 2 The effect of different plant densities on cucumber leaf stomatal conductance



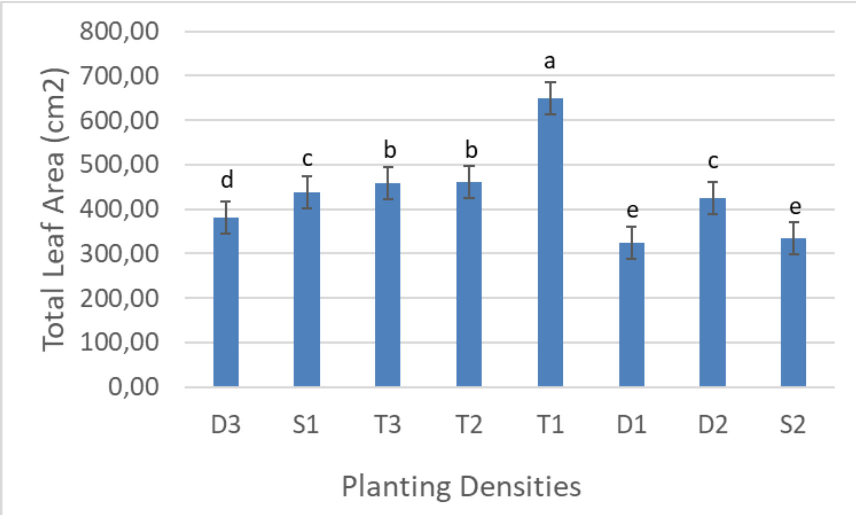
Stomata play a vital role in the balance between water loss and photosynthesis efficiency. Environmental factors, particularly light and CO_2, play an important role in this balance. Environmental factors transmit systemic signals, and mature leaves perceive these signals better. While increased light quantity increases stomatal movements, high CO_2 concentration decreases stomatal movements. Additionally, increased humidity also reduces stomatal movements (Casson and Gray, 2008). Approximately 85-90% of water loss in plants occurs through stomata. Therefore, it is necessary to know the numbers and structures of stomata found in the leaves of each crop plant. Stomata are organs that regulate transpiration and are also gateways that enable gas exchange between the plant's internal tissues and the external environment. Stomata regulate transpiration by opening and closing according to various conditions. In this way, plants continue their lives without experiencing excessive water loss (Dickison, 2000).

In applications with higher plant density such as T3, limitations in the amount of water per plant or competition in the root zone may have created a physiological response aimed at preventing the plant from losing water by reducing stomatal conductance. The obtained findings reveal that plant physiology is suppressed as plant density increases and are consistent with findings from previous studies.

Leaf Area

In the study, the effects of different planting densities on leaf area in organic cucumber were examined. When the leaf areas obtained from measurements made on cucumber leaves were examined, the largest area was calculated as 285.5 cm^2 for lower leaves in T1, 218.1 cm^2 for middle leaves in T1, and 185.5 cm^2 for upper leaves in S1 plants. When looking at the smallest areas, the D1 application appears with 80.4 cm^2 in lower leaves, S2 with 81.1 cm^2 in middle leaves, and D3 with 116.2 cm^2 in upper leaves. While lower leaf area values were obtained in lower leaves, middle and upper leaves had higher leaf area values compared to lower leaves. When the total leaf area values calculated based on these three leaf area values were examined, the T1 application was in the statistically significant group compared to other planting applications, while S2 and D1 applications were in the group with the lowest values (Graph 3). The low values in the D1 application reveal that when the number of plants per unit area increases, each plant is able to develop less leaf area (Tafoya et al., 2019). Leaf area determines the plant's capacity to capture light energy, which is important for photosynthesis (Peil et al., 2014).

Graph 3 The effect of different plant densities on cucumber total leaf area

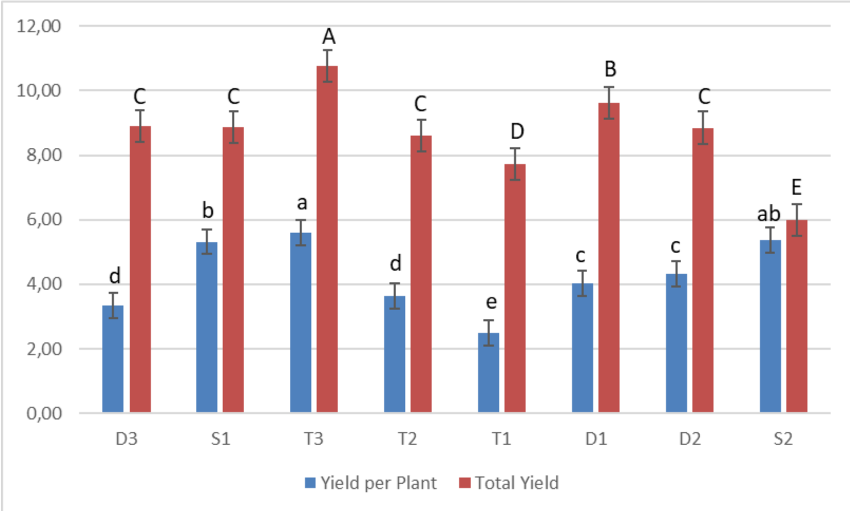


The 216.60 cm² area in T1 may be the point where the plant's light utilization potential is highest. Marcelis et al. (2005) state that a 1% increase in leaf area can provide a 0.7-1% increase in yield. However, when leaves begin to shade each other, the yield increase is not expected to continue. Consequently, at low plant densities, important parameters related to photosynthesis and yield, such as leaf area, are expected to increase (Gomes et al., 2017).

Yield per Plant, Total Yield

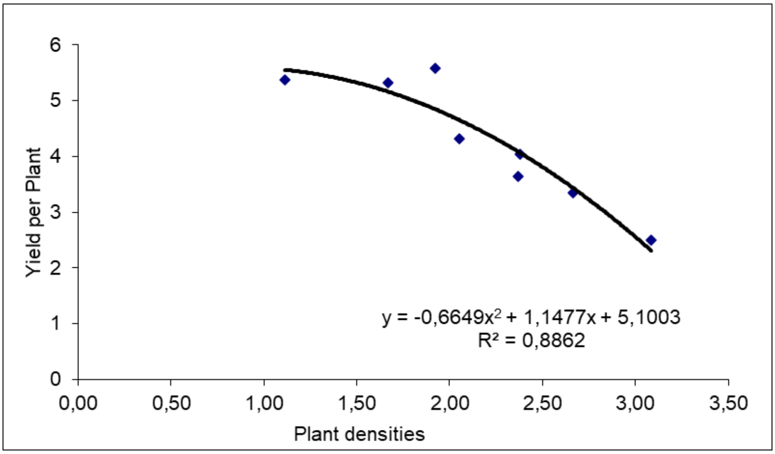
The findings obtained from the study showed that different applications had statistically significant effects on both yield per plant (YPP) and total yield (TY) ($p<0.05$). The highest yield per plant was obtained in the T3 application with 5.59 kg, and this application showed statistically superior performance compared to all other applications. The yield per plant of the D3 application, which was the control group, was recorded as 3.34 kg. All of the T3, S2, S1, D2, and D1 applications provided higher yield per plant than the control group.

Graph 4 The effect of different plant densities on yield values



The S2 application exhibited the closest performance to T3 with 5.38 kg. The lowest yield per plant value was observed in the T1 application with 2.50 kg. The increase in plant density in cucumber decreased yield per plant in a curvilinear manner. The degree of relationship (r^2) between plant density and yield per plant was 0.88. The total yield results show that area-based production capacity varies significantly according to applications. The T3 application ranked first statistically by achieving the highest value in both yield per plant and total yield with 10.76 tons/da. T3 is followed by the D1 application with a yield of 9.61 tons/da. Total yield in the D3 application, which was the control group, was determined as 8.91 tons/da. The S1 (8.86 tons/da), D2 (8.85 tons/da), and T2 (8.62 tons/da) applications were in the same statistical group as the control group, offering similar yield levels. The application with the lowest total yield was S2 with 5.98 tons/da. The data prove that the T3 application is the most ideal method in terms of both individual plant productivity and total area productivity. It is observed that it provides approximately a 20% increase in total yield compared to the control group (D3) in particular.

Graph 5 The relationship between plant density and cucumber leaf chlorophyll content



Researchers have demonstrated that yield per plant changes with the adjustment of plant density; as plant density increases, yield per plant has increased, thus enabling an increase in total yield. Increasing the number of plants per unit area generally also increases total yield (Echevarria and Castro, 2002; Ganesan et al., 2004; Parks et al., 2019; Tafoya et al., 2019; Kumar et al., 2024).

Doaris et al. (1991), Pearson (1992), and Uzun (1996) discovered in their studies on various species that total yield increased with increasing light intensity. Cocshull et al. (1992) stated that a 1% increase in lighting throughout the growing season increased yield by approximately 1%, and they attributed this yield increase to an increase in average fruit weight. Numerous researchers have indicated that total yield increases with increasing plant density (Papadopulos and Ormrod, 1991; Echevarria and Castro, 2002; Parks et al., 2019; Tafoya et al., 2019).

In summary, the T3 application has values that constitute a concrete example of yield increase dependent on plant density increase as stated in the literature. It has reached maximum values in both yield per plant and total yield.

Correlations Among the Traits Examined in the Research

In the research, correlation analysis was conducted to reveal the relationships among the characteristics examined in organic cucumber cultivation in the greenhouse. Detailed results of these relationships are given in Table 3. Among the examined characteristics, it was determined that there was a positive and significant correlation relationship at the $p<0.05$ level between leaf chlorophyll content and yield per plant in cucumber plants (Table 3). This situation proves that the increase in chlorophyll density in the leaf directly increases photosynthetic capacity, thereby elevating fruit weight/number per plant.

Table 3 Correlations among the traits examined in the research

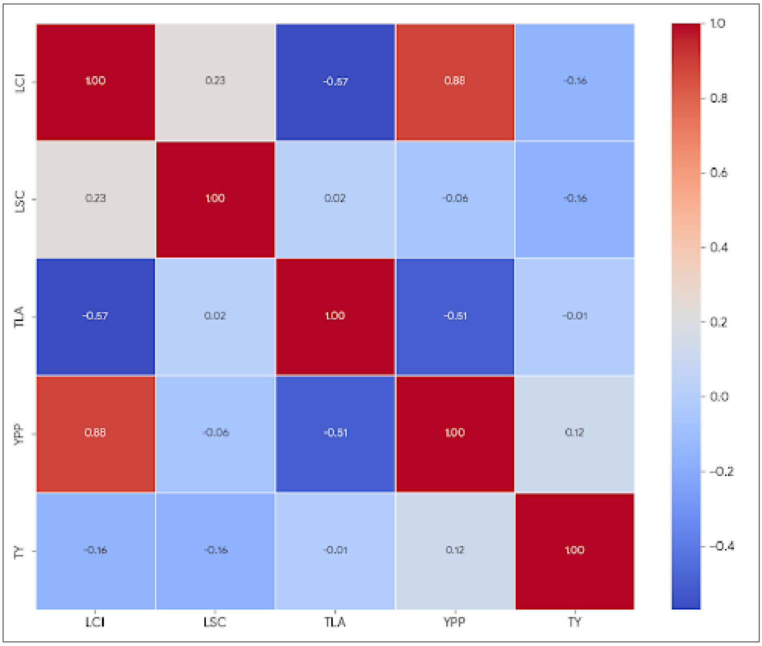
	YPP	**TY**	**LCI**	**LSC**	**ALA**
YPP	1.00	0.11	0.88*	-0.05	-0.50
TY	0.11	1.00	-0.15	-0.16	-0.00
LCI	0.88*	-0.15	1.00	0.23	-0.57
LSC	-0.05	-0.16	0.23	1.00	0.02
ALA	-0.50	-0.00	-0.57	0.02	1.00

***p<0.01, LCI: Leaf chlorophyll index, LSC: Leaf stomatal conductance, ALA: Average leaf area, YPP: Yield per plant, TY: Total yield**

The negative correlation between average leaf area (ALA) and yield (YPP) shows that the plant's expenditure of energy on excessive vegetative growth (leaf area) can suppress yield. The enormous leaves observed especially in the T1 application confirm this negative relationship. The weak correlation between yield per plant and total yield is quite critical. This finding shows that total area productivity depends not only on individual plant performance but also probably on responses to planting density or environmental factors (For example, although yield per plant is high in the S2 application, total yield is low). The fact that stomatal conductance does not show a direct correlation with yield indicates that although plants follow different transpiration strategies, they can achieve similar yields, and that "carbon capture capacity" (LCI) is more determinative than "water loss rate" for yield.

According to the study results, it can be recommended to prefer applications (such as T3) that will keep leaf area (ALA) under control and maximize chlorophyll density (LCI) to increase yield.

Graph 6 Correlation matrix



Conclusion

The study demonstrated that different planting systems and plant densities significantly affected physiological parameters and yield in organic cucumber cultivation under greenhouse conditions. Among the tested applications, the T3 application (triangular row with 2.67 plants/m² density) consistently showed superior performance, with the highest yield per plant and total yield obtained from this application. This application also optimally balanced leaf chlorophyll content and stomatal conductance, providing better photosynthetic efficiency.

Increasing plant density generally increased total yield per area, but tended to reduce individual plant performance indicators such as chlorophyll content and leaf area due to increased intra-plant competition and light limitation. The negative correlation observed between leaf area and yield indicates that excessive vegetative growth can negatively affect fruit production. Additionally, stomatal conductance did not show a strong correlation with yield. This indicates that carbon assimilation capacity (associated with chlorophyll content) is more critical for productivity.

These findings emphasize the importance of selecting appropriate planting systems and densities to optimize light reception, physiological function, and resource allocation in organic cucumber production in greenhouses. The T3 planting system emerges as a promising approach to maximize both individual plant and overall crop productivity. Future cultivation strategies should prioritize balancing plant density to prevent excessive shading and competition while promoting efficient photosynthesis and resource use.

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BÖLÜM 2

EFFECT OF GIBBERELLIC ACID APPLICATIONS ON YIELD AND SOME BIOCHEMICAL CONTENTS IN SAKIZ AND BAYRAMPAŞA ARTICHOKE CULTIVARS[1]

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1- INTRODUCTION

Fruits and vegetables are sources that benefit human health due to their rich content of phytochemicals such as vitamins, minerals, dietary fiber, carotenoids, and antioxidant compounds (Ceccarelli et al., 2010; Yahia et al., 2019). In recent years, studies in the field of health have indicated that fruit and vegetable

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consumption within the Mediterranean diet is effective in reducing the risk of cancer and cardiovascular diseases. The consumption of certain plant sources provides a healthy dietary strategy and plays an important role in preventing chronic diseases such as heart disease, cancer, stroke, diabetes, Alzheimer's disease, cataracts, and age-related functional decline (Liu, 2013).

Artichoke, a traditional component of the Mediterranean diet, is accepted as a functional food according to the definition of the European Commission on Functional Food Science in Europe. From a nutritional perspective, artichoke is a plant-based food whose natural components have positive effects on specific target functions beyond basic nutritional values, thereby reducing the risk of certain diseases (Ceccarelli et al., 2010).

When global artichoke production areas are examined, the Mediterranean basin is seen to be the region with the largest production area. In this region, artichoke consumption began during the periods of the ancient Greeks and Romans and has remained on distinguished tables to the present day (Vural et al., 2000). It has long been regarded as an important plant and has been the centerpiece of royal tables. It is known that the Egyptian king Ptolemy fed artichokes to his soldiers to boost their courage. With the discovery of America, artichoke was introduced to the Americas by the Spanish. Produced for many years in limited areas along the California coast, artichoke became popular in the United States when Marilyn Monroe (Norma Jeane Mortenson) was crowned Artichoke Queen at a festival held in Castroville in 1948. Castroville is still referred to as the artichoke center of the world. Today, Mediterranean countries are the leading producers and consumers of artichoke worldwide (Sonnante et al., 2007). Italy, Egypt, Spain, France, Greece, Türkiye, Israel, the USA, Chile, Peru, and Argentina are among the major artichoke-producing countries (Sgroi et al., 2015). In Italy, France, and Spain, artichoke appears in folk culture, riddles, legends, paintings, ornaments, and ancient mosaics, occupying diverse aspects of daily life and culture. In Italy alone, more than 1.300 dishes are prepared with artichoke (Bianco, 2012).

Artichoke is primarily cultivated for its large immature flower heads. Depending on the culture, flower stalks and leaf stalks are also consumed in different ways. The edible parts are the receptacle, commonly known as the “heart,” which constitutes approximately 35–55% of the fresh head weight (Ceccarelli et al., 2010). Consumption as olive oil dishes, grilled artichokes, and canned products is widespread. Large Sakız artichokes are commonly consumed as stuffed dishes, and they are also prepared with chicken or lamb meat. In the Aegean region, artichoke cooked with olive oil, abundant lemon, dill, and fava beans is preferred. With its unique taste and aroma, artichoke is indispensable on tables (Eser et al., 2006). In recent years, increasing awareness of its health effects has led to growing global interest in artichoke. Fresh artichoke contains 10–12% dry matter per 100 g, with 88–90% water, 2–3 g protein, 0.5–2 g sugar, and 0.2–0.3 g fat (Vural et al., 2000; Eser et al., 2006; Ceccarelli et al., 2010). Artichoke is rich in B and C vitamins and has high contents of calcium, potassium, iron, magnesium, and phosphorus (Ayuso et al., 2024). Experimental studies on rats and laboratory research have scientifically demonstrated that artichoke is a highly liver-friendly vegetable. Due to its cynarin content, it significantly reduces bad cholesterol levels, helps regulate blood sugar, and purifies the blood (Gebhardt & Fausel, 1997). With its many phytochemicals, artichoke exhibits antioxidant effects. In a study conducted by Pérez-García et al. (2000), the antioxidant activities of artichokes in human leukocytes were also investigated, and it was reported that reactive oxygen species (ROS)-induced oxidative stress was inhibited by cynarin, caffeic acid, chlorogenic acid, and the flavonoid luteolin. Compared with other vegetables, artichoke heads possess hepatoprotective, hypocholesterolemic, and antioxidant properties and contain high levels of total polyphenols (Brat et al., 2006; Ceccarelli et al., 2010; De Falco et al., 2015; Lattanzio et al., 2009; Mulinacci et al., 2004; Schütz et al., 2004).

The availability of fresh table artichokes is limited to certain periods due to climatic conditions. Along with developments in social life, the emergence of healthy nutrition practices has changed dietary behaviors, and artichoke has become prominent among health-friendly products. In Türkiye, artichoke is generally considered part of Mediterranean-style nutrition, and its consumption has rapidly increased in recent years (Ugur & Eser, 2013; Zeybekoglu & Ugur, 2013). Fresh table artichokes are mainly produced in Izmir and Aydın, while canned artichokes are produced more in Bursa. The early table variety Sakız artichoke has been registered with a geographical indication by the İzmir Commodity Exchange under the name "Urla Sakız Artichoke." In the Marmara region, Bayrampaşa and local varieties are preferred for canning, although in recent years hybrid artichoke varieties for table and canning purposes have also been used (Duman et al., 2020). Under İzmir conditions, a commercial artichoke heart variety tested for five years had an average head weight of 29.77–45.37 g, with the highest head yield (21,666 heads/da) determined in the second year (Duman & Nas, 2020).

Sakız artichoke has a fresh and juicy appearance, lower fiber content, and does not develop spines associated with high temperatures in early harvests. Consumers consistently demand fresh artichokes, which can fetch high prices in markets. Due to climatic advantages, the Mediterranean region stands out in early artichoke production (Ilbi et al., 2007). However, the early increase in spring temperatures after April limits fresh artichoke production along coastal areas. For early production, plants that enter dormancy during summer must be reactivated by irrigation, which should be carried out in the first half of August. Without irrigation, plants only become active with autumn rains, eliminating earliness. Expected early harvests in late January–early February may shift to late March. Optimal growth occurs at temperatures of 15–18 °C, while temperatures above 25 °C stop growth. Temperatures dropping to 0 °C cause severe damage, leading to head deformation and, depending on exposure duration, plant death. Autumn frosts in artichoke-growing regions also cause significant damage. In early varieties, the formation of early and extra-early products is prevented. Dry and hot spring conditions cause smaller heads, reduced crispness, bitterness, and fiber formation, especially in late canning varieties, leading to rapid flowering and yield loss (Eser et al., 2006). In the Aegean and Mediterranean regions, early spring temperature increases limit fresh artichoke production after April, while high summer temperatures (>35 °C) hinder table artichoke production. In contrast, the Central Black Sea region receives rainfall throughout the year, with July being the driest month and an average temperature of 22.1 °C, without extreme summer heat or large diurnal temperature differences. With careful irrigation and cultural practices, plants can be maintained in active growth without stress, allowing new shoot and head formation. Due to different yield behaviors of Sakız and Bayrampaşa varieties, a longer harvest period is possible. Harvest time and head quality are also affected by gibberellic acid (GA3) doses.

The main objective of this study was to investigate the extension of the harvest period in fresh table artichoke production and to evaluate yield distribution as well as changes in head quality and antioxidant contents.

2- MATERIALS AND METHODS

Within the scope of the study, the effects of GA3 applications on yield and quality characteristics of Sakız and Bayrampaşa artichoke cultivars grown in the Central Black Sea coastal belt were determined. The experimental plots were established at the trial field of the Provincial Directorate of Agriculture and Forestry in Altınordu district, Ordu province. The soil was plowed to a depth of 30–40 cm at the end of September under suitable moisture conditions and leveled afterward. Raised beds 30 cm high and 70 cm wide with 30 cm spacing were prepared. The experiment was conducted in a randomized complete block design with three replications. Plant spacing was 1 × 1 m. Each row consisted of 20 plants and was considered a plot, with one row left as a border. NPK fertilization was applied at 15/10/15 kg/da using ammonium nitrate, TSP, and potassium sulfate. All TSP was applied before planting, while the other fertilizers were applied in five equal doses at 20, 40, 150, 180, and 200 days after planting. All cultural practices, irrigation, and fertilization were carried out according to Vural et al. (2000).

GA3 was applied as a spray at 0, 25, and 50 ppm on March 30, when the main shoot began to appear in the central crown. Heads reaching harvest size (>7 cm diameter) were harvested. The number of days to first main head appearance, first harvest date, number of harvested heads, and first main head height were recorded. Total number and weight of harvested heads were determined. In June, when harvest was most intensive, 10 representative heads per replication were evaluated for head weight, height, width, and spinosity. Head weight was measured using a precision balance, and head dimensions were measured with a digital caliper. Spinosity was assessed by gently pressing the upper part of the head into the palm. Antioxidant contents were also determined (Eser et al., 2006).

Total antioxidant activity was determined by DPPH· free radical scavenging activity using the modified method of Demirtaş et al. (2013) based on Blois (1958). Absorbance was measured at 517 nm, and results were expressed as μmol Trolox equivalents (TE) g^{-1} fresh weight. FRAP (Ferric Reducing Antioxidant Power) analysis was conducted following Benzie & Strain (1996), with absorbance measured at 593 nm and results expressed as μmol TE g^{-1} fresh sample.

Simple statistics and analysis of variance were performed. Differences among treatments were evaluated using Tukey's multiple comparison test at a significance level of $\alpha = 0.05$ using SPSS 22.0.

3- RESULTS AND DISCUSSION

The effects of GA3 applications on yield and some biochemical contents of the Sakız cultivar are presented in Table 1.

Table 1. Plant yield values and biochemical contents of GA3 applications in Sakız varieties

Sakız variety	Treatment	Mean	Standard deviation	Minimum	Maxsimum
Head weight (g)	Control	409.02 b	21.07	393.14	432.92
	GA3 25 ppm	404.81 b	2.53	401.97	406.84
	GA3 50 ppm	497.47 a	32.26	460.52	520.05
	LSD	***			
Head length (cm)	Control	8.22	0.19	8.00	8.33
	GA3 25 ppm	8.11	0.19	8.00	8.33
	GA3 50 ppm	8.39	0.22	8.17	8.50
	LSD	ns.			
Head width (cm)	Control	10.94 b	0.38	10.50	11.17
	GA3 25 ppm	11.33 b	0.17	11.17	11.50
	GA3 50 ppm	12.22 a	0.63	11.50	12.67
	LSD	*			
DPPH (mg 100 g^{-1})	Control	325.29 a	29.90	295.39	355.19
	GA3 25 ppm	283.94 a	18.26	265.69	302.20
	GA3 50 ppm	227.41 b	22.46	205.69	250.54
	LSD	***			
Phenolic (mg 100 g^{-1})	Control	164.28 c	8.01	156.00	172.00
	GA3 25 ppm	182.16 b	5.39	176.00	186.00
	GA3 50 ppm	214.41 a	11.27	202.00	224.00
	LSD	***			

Flavonoid (mg 100 g^{-1})	Control	73.81 b	5.06	68.46	78.52
	GA3 25 ppm	157.47 a	11.15	145.12	166.80
	GA3 50 ppm	62.19 b	8.16	56.28	71.50
	LSD	***			
Yield (heads/da)	Control	1800.00 a	200.00	1600.00	2000.00
	GA3 25 ppm	1466.67 b	116.00	1400.00	1600.00
	GA3 50 ppm	1533.33 ab	116.00	1400.00	1600.00
	LSD	*			
	ns.; not significant, *; p≤0.05 **; p≤0.01 ***; p≤0.001				

According to GA3 applications, changes were observed in head weight, head width, DPPH, phenolic content, flavonoid content, and yield values in the Sakız variety. GA3 application in the Sakız variety caused a decrease in yield values. The highest yield was determined in the control application with 1800 heads/da, but larger heads were observed in GA3 applications. The GA3 50 ppm application stood out in head weight, head length, head width, and phenolic content. Keskin & Namal (2019) determined that in Antalya conditions, under different fertilization applications, the main heads of Sakız artichoke plants ranged between 633.7-710 g, head width varied between 127-139.5 mm, and head length varied between 124-133 mm. These values were found to be higher than our results. It is thought that the slightly milder winter conditions in the Antalya ecology compared to our region led to these results. These values were determined to be high according to our results. It is thought that the slightly milder winter conditions in the Antalya ecology compared to our region led to these results. In our study, the control application yielded higher values in DPPH and yield values. On the other hand, the phenolic content was found to be highest in the 0 ppm GA3 application and lowest in the control application. In terms of flavonoid content, the 25 ppm GA3 application was significantly superior to other applications. When reviewing the relevant literature on biochemical content, ecological differences and varieties are seen as the main factors (Dabbou et al., 2017; Kayahan & Saloğlu, 2021). Antioxidant activity plays a crucial role in evaluating vegetable quality, as antioxidant molecules contribute to plant growth and development under stressful conditions and promote health benefits in human nutrition. It is thought that the cooler climate of our region compared to traditional artichoke-growing areas is a contributing factor in this case.

The effects of GA3 applications on the Bayrampaşa cultivar are presented in Table 2.

Table 2. Plant yield values and biochemical contents of GA3 applications in Bayrampaşa variety

Bayrampaşa variety	Treatment	Mean	Standard deviation	Minimum	Maxsimum
Head weight (g)	Control	349.36 b	11.46	336.20	357.15
	GA3 25 ppm	325.46 c	6.28	318.47	330.64
	GA3 50 ppm	406.31 a	16.01	396.94	424.79
	LSD	***			
Head length (cm)	Control	8.00 ab	0.17	7.83	8.17
	GA3 25 ppm	7.50 b	0.44	7.00	7.83
	GA3 50 ppm	8.22 a	0.09	8.17	8.33
	LSD	*			
Head width (cm)	Control	10.78 a	0.19	10.67	11.00
	GA3 25 ppm	9.84 b	0.58	9.17	10.17
	GA3 50 ppm	11.28 a	0.42	10.83	11.67
	LSD	***			
DPPH (mg 100 g^{-1})	Control	282.78 a	24.09	255.79	302.10
	GA3 25 ppm	276.21 a	12.15	265.49	289.41
	GA3 50 ppm	138.50 b	16.45	121.96	154.85
	LSD	***			
Phenolic (mg 100 g^{-1})	Control	176.52 b	17.37	158.48	193.14
	GA3 25 ppm	114.04 c	16.74	102.94	133.30
	GA3 50 ppm	305.47 a	24.49	281.16	330.14
	LSD	***			

Flavonoid (mg 100 g^{-1})	Control	125.06 a	7.60	116.72	131.60
	GA3 25 ppm	82.13 c	5.65	77.58	88.46
	GA3 50 ppm	100.31 b	9.64	90.48	109.74
	LSD	***			
Yield (heads/da)	Control	1666	116	1600	1800
	GA3 25 ppm	1800	200	1600	2000
	GA3 50 ppm	1866	116	1800	2000
	LSD	ns.			
	ns.; not significant, *; p≤0.05 **; p≤0.01 ***; p≤0.001				

According to GA3 applications, changes were observed in head weight, head length, head width, DPPH, phenolic content, and flavonoid content values in the Bayrampaşa variety. The GA3 50 ppm application was found to have higher values for head weight, head length, head width, and phenolic content. Artichokes in the control application had higher values for DPPH and flavonoid content. The biochemical contents obtained from the study were found to be slightly lower than those reported in the literature (Bonasia et al., 2023; Kayahan & Saloğlu, 2021). It is known that biochemical contents are high under stress conditions and in hot climates. The fact that our region has a cool climate suggests that this may be the reason for the low biochemical contents. Biochemical contents were found to be higher in purple-colored varieties (Bonasia et al., 2023). Ecology and genotypes are seen as absolutely effective factors in yield values.

4- CONCLUSION

It was determined that Sakız and Bayrampaşa artichoke cultivars enter mid-season production under Central Black Sea ecological conditions, with limited earliness compared to traditional perennial cultivation. Considering the climatic data of the region, it is suggested that an alternative production model using seedlings or rooted vegetative parts established in late spring could allow autumn harvests. The effects of GA3 applications varied, particularly in the first year due to developmental variability in newly established plantations. Evaluating the subject in multi-year plantations may provide broader perspectives.

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BÖLÜM 3

Morphological Characterization of Androgenic Pure Lines in Hatay Type Hot Peppers

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INTRODUCTION

Pepper (*Capsicum annuum* L.) is an economically important species within the Solanaceae family. Of the approximately 37 million tons of peppers produced globally each year, around 17 million tons are contributed by China. Following Mexico and

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Indonesia, Türkiye ranks fourth in global production with 2.7 million tons, while Spain ranks fifth with a somewhat lower production volume (FAO, 2024). Collectively, these five countries account for 72.92% of total global pepper production.

Pepper (*Capsicum* spp.) is believed to have originated in the tropical and subtropical regions of Central and South America. It was among the earliest crops domesticated by humans (McLeod et al., 1982; Pickersgill, 1988; Perry et al., 2007). After its introduction to the Old World by the Spanish, it was reportedly cultivated in Hungary as early as the 16th century (Somos, 1984). Around the same period, it was also grown in Anatolia and the Balkans. Its transmission to Asia via Anatolia played a key role in the global dissemination of the species (Katz, 2009).

Today, pepper is consumed in diverse forms and is also recognized as a functional food product. It is cultivated in nearly every country worldwide, and Anatolia possesses a rich diversity of genetic resources. Among the chili pepper group, Hatay peppers, extensively grown in the Samandağ region, represent one of these valuable resources. However, open-pollinated (OP) varieties with improved quality are often sensitive to biotic stress factors and lack sufficient uniformity. As a result, hybrid pepper production has become increasingly prevalent worldwide, owing to its potential for higher yields, improved disease resistance, and enhanced marketability. The global hybrid pepper market is expected to continue expanding as growers seek cultivars that combine greater productivity with improved resilience to environmental stresses.

Breeding strategies focus on producing varieties that meet growers' requirements in terms of yield, fruit quality, and disease resistance. Developing pepper varieties with consistent pungency and minimal susceptibility to seasonal variations is also essential. The accelerated development of new varieties relies on advanced technological methods and the identification of parental lines exhibiting superior heterosis when crossed. Understanding the genetic relatedness within the gene pool is critical for designing effective breeding programs, as the relationship between parents directly influences the productivity and quality of F1 hybrids. The magnitude of these effects depends on the degree of relatedness and distance between parental lines.

Creating heterotic groups and evaluating heterosis and combining ability significantly enhance breeding success (Nacar, 2014). The formation of heterotic groups is a technique that accelerates breeding programs by identifying which parental combinations are likely to produce heterosis. The magnitude of the heterosis effect is associated with the degree of relatedness between the parents. In general, the lower the genetic relatedness — that is, the greater the genetic distance (up to an optimal point) — the higher the heterosis effect observed. Conversely, crosses between closely related parents tend to exhibit reduced heterosis (Onus and Abak, 2022). These methods facilitate breeding and increase the probability of success within a shorter time frame (Doğangüzel et al., 2022).

Morphological characterization is an effective approach for assessing genetic relatedness and guiding hybrid variety development. For instance, Boyacı et al. (2020) examined 62 pure lines of *Solanum melongena* for 32 morphological traits and used cluster analysis to identify heterotic groups. Their findings demonstrated that this approach effectively supports the creation of superior hybrid combinations. Öntürk and Çürük (2019) investigated traits such as plant height, stem and leaf hairiness, stem color and shape, as well as leaf, flower, and fruit characteristics in pepper populations from the Hatay region. In Samandağ pepper, the study reported lower variation compared to other groups. Fruits were generally elongated, flower tips were pointed, and pungency was notably high. Several studies have employed morphological characterization based on UPOV criteria to evaluate different pepper populations, including those conducted by Mutlu et al. (2009), Binbir and Baş (2010), Ermiş et al. (2010), Arpacı et al. (2017), Başak (2019), Taş and Balkaya (2021), Kanal and Balkaya (2021), Şahin et al. (2022), and Duruk and Pınar (2023).

In this study, the main approach was employed to identify potential parental lines among Hatay pepper pure lines (DHs) carrying *Tsw* resistance genes. For this purpose, morphological characterization was performed based on 30 traits, followed by the construction of dendrograms to obtain fundamental information the genetic relatedness within androgenic Hatay pepper lines

Materials and Methods

Plant Material

This study was conducted at the AG Seed R&D station, which has a 50-decare research greenhouse located in the Kurşunlu area of Antalya. The plant material used consisted of 90 dihaploid (DH) pepper lines obtained within the scope of the TUBİTAK 1507 project (Project No: 7210289) previously conducted and completed at AG Seed (Figure 1).

Hatay Samandağ peppers represent a highly pungent village population. Their most notable characteristics are a relatively thin fruit flesh and medium-long fruit size. The plant material was derived from a gene pool created by crossing Hatay peppers with varieties tolerant to Tomato Spotted Wilt Virus (TSWV), a major pathogen causing significant damage in peppers. From this population, pure lines were developed using DH technology as detailed in our previous study (Nar et al., 2023).

Methods

Plant Cultivation and Transplanting

For each line, 54 seeds were sown in plastic germination trays filled with sterile peat. Seedlings were subsequently transplanted into trays containing a 1:1 mixture of locally sourced peat and perlite, sterilized by steam. During the seedling stage, plants were irrigated and supplied with nutrient-enriched water until they developed 3–4 true leaves, ensuring proper care throughout this period. When seedlings reached the 4–5 true leaf stage, they were transferred to the greenhouse for further growth.

The experiment was conducted during the spring growing season in a plastic-covered greenhouse. A randomized complete block design with three replications was employed. Plants were transplanted in a double-row arrangement with 100 × 50 × 60 cm spacing, using 15 plants per genotype. Throughout the growing period, cultural practices—including irrigation, fertilization, pruning, and control of diseases and pests—were applied to maintain optimal plant growth and health.

Morphological Characterization

For the characterization of the lines, 30 morphological traits were evaluated in accordance with the criteria specified by UPOV (International Union for the Protection of New Varieties of Plants), the Turkish Ministry of Food, Agriculture, and Livestock's "Regulation on Plant Characteristics" (translated into Turkish and enacted in 2007), the International Plant Genetic Resources Institute (IPGRI), and the "Technical Instruction for Measuring Agricultural Values" published by the Seed Registration and Certification Center (TTSM). The 17 morphological traits evaluated using 17 scales are presented in Table 1. Observations and measurements were conducted on 10 plants and 6 fruits per replication for each trait. In addition, the characteristics plant height, stem thickness, leaf index, fruit length, fruit diameter, fruit shape index, fruit peduncle length, fruit flesh thickness, placenta length, number of fruits per plant, average fruit weight, total yield, and yield per plant were also measured and determined.

One-way analysis of variance (ANOVA) was performed to evaluate differences between applications and genotypes. The general linear model procedure of SPSS (Statistics 20) software (IBM Corp., Armonk, NY, USA) was used for data analysis. All main effects were considered as fixed effects. Tukey's multiple range post hoc test was employed for multiple comparisons of the genotypes and media and t-test for seasons with an alpha level of 0.05.

Genetic similarity was assessed using the UPGMA (Unweighted Pair-Group Method with Arithmetic Mean) clustering approach through the NTSYS software (Numerical Taxonomy and Multivariate Analysis System, PC version 2.2; Rohlf, 1998), based on both morphological and molecular data. For the morphological traits, each genotype was assigned a description number (Table 1). Dendrograms were constructed using the UPGMA clustering method implemented in the SHAN module

Results and Discussion

In the study, it was determined that the mean plant height of the lines ranged from 58 cm to 142 cm (Fig. 2). The highest plant height was observed in genotype AD90 (142 cm), followed by AD88 and AD85. The shortest plant height was recorded in AD46. Padilha et al. (2016) reported that plant height in *C. annuum* genotypes ranged between 23.12 and 48.72 cm, while Sreenivas et al. (2019) found values between 37.6 and 110.6 cm. Mavi and Mavi (2015) reported a range of 14.3–77.3 cm in ornamental peppers, Özgüven and Yaldız (2011) reported 37.67–117.7 cm in *C. frutescens*, Taş (2020) 30.5–106.0 cm in *C. chinense*, and Patel et al. (2016) 27–125 cm in *C. baccatum* genotypes.

Statistically significant differences were determined among the lines in terms of stem thickness. The thickest stem was observed in AD69 (1.96 cm), while the thinnest was found in AD75 (0.97 cm). The line with the highest leaf index was AD28. Genotypes AD10, AD16, AD25, AD35, AD40, and AD53 also exhibited relatively high leaf index values. The differences among AD84, AD74, and AD78 were not statistically significant, and these lines had the lowest leaf index values. When the plants reached harvest maturity, the leaf index was determined by measuring the ratio of average leaf length to leaf width (cm) from eight fully developed middle leaves using a digital caliper. The differences obtained in terms of leaf index are graphically presented in Figure 3.

Statistically significant differences were found among the 90 DH lines in terms of plant height, stem thickness, and leaf index, indicating that these parameters could serve as useful criteria for determining variation among genotypes. In addition, clear differences were observed among the lines with respect to fruit length, fruit diameter, fruit index, and fruit peduncle length. The mean fruit length of the lines ranged from 90.93 mm to 224.09 mm. The longest fruit was recorded in line AD37 (224.09 mm), followed by AD30 (222.94 mm), while the shortest fruit was observed in AD88 (90.93 mm). Koç (2022) reported that in a comparative study of Kilis and Elbeyli peppers, fruit lengths ranged from 111.3 to 208.9 mm in Kilis genotypes and 68.8 to 127.9 mm in Elbeyli genotypes. Similarly, Öntürk (2018) reported that fruit length values of 16 pepper genotypes collected from different regions of Hatay province ranged between 133.6 mm and 210.8 mm.

Significant differences in fruit diameter were observed among the lines, ranging from 20.49 mm to 34.96 mm. The highest fruit diameter was recorded in line AD89 (34.96 mm), followed by AD36 (34.93 mm), while the lowest fruit diameter was measured in line AD49 (20.49 mm). These findings indicate that genetic diversity has a considerable influence on fruit diameter and that this trait should be considered an important criterion in selection studies.

Similarly, Yayman et al. (2024) reported that among 12 genotypes selected from Kahramanmaraş pepper populations and 4 registered pepper cultivars, the highest fruit diameter was observed in the cultivar 'Dila' (23 mm), while the lowest was recorded in line 378 (15.84 mm).

When the fruit shape index was examined, the highest value was recorded in line AD16 (9.48 mm), while the lowest value was observed in AD88 (3.33 mm) (Fig.4). In a study conducted by Özgen and Balkaya (2021), the fruit shape index of hybrid sweet pepper cultivar candidates ranged between 1.11 mm and 1.61 mm; however, these differences were not found to be statistically significant.

The fruit peduncle length ranged from 31.37 mm to 70.88 mm. The shortest fruit peduncle length was measured in line AD36, while the longest was recorded in line AD88 (70.88 mm). In a study conducted by Gökmen (2018), the fruit peduncle length of peppers belonging to seven çarliston types among the materials that included 23 local lines and 9 F_1 genotypes ranged from 3.5 cm to 4.88 cm. In bell pepper types, these values were found to range between 30.72 mm and 45.44 mm (Özgen ve Balkaya, 2021). In another study conducted on Hatay pepper genotypes, fruit peduncle lengths were measured to range between 34.5 mm and 57.5 mm (Öntürk ve Çürük, 2019). Therefore, morphological parameters such as fruit length, fruit diameter, and peduncle length were identified as characteristics that reveal genetic diversity.

In Hatay-type peppers, fruit flesh thickness—one of the most important selection criteria—affects eating quality, while placenta length influences both the level and distribution of pungency within the fruit. Fruit weight and number are key factors determining yield, making all these traits highly preferred characteristics for both consumers and producers. The mean fruit flesh thickness of the DH lines ranged from 2.57 mm to 4.63 mm. Line AD4 had the thickest fruit flesh (4.63 mm), while lines AD13 and AD55 had the thinnest

(2.57 mm) (Fig.5). Various studies have reported fruit flesh thickness values in peppers ranging between 0.78–2.44 mm (Dilfiruz and Pınar, 2022), 1.62–2.80 mm (Altuntaş et al., 2021), 1.17–2.76 mm (Tatar, 2022), and 0.9–4.88 mm (Khan et al., 2025). Differences in pepper fruit segments are known to influence fruit flesh thickness.

Among the DH lines, placenta length varied between 23.60 mm and 151.00 mm. The longest placenta was observed in line AD19, while the shortest was recorded in AD88. Longitudinal-sections of the DH line fruits are presented in Figure 6. A relationship has been observed between placenta length and pungency in peppers. The placenta is the primary site of capsaicinoid biosynthesis and accumulation, and numerous studies have reported that it contains the highest concentration of capsaicinoids within the fruit (Pandhair and Sharma, 2008; Cervantes-Hernández et al., 2019; Zamljen et al., 2020; Vázquez-Espinosa et al., 2023). This anatomical feature is therefore considered an important determinant of fruit pungency in Capsicum species.

Gülcan (2020) reported the longest placenta length as 32.7 mm in the local *Çine* pepper cultivar, while the shortest value (25.5 mm) was found in a standard open-pollinated (OP) pepper variety.

Significant differences were observed among the lines in terms of fruit weight. The highest average fruit weight was recorded in line AD36 (81.00 g), followed by AD4 (77.40 g). The lowest average fruit weight was found in line AD44 (14.80 g). When the number of fruits per plant was examined, the highest value was observed in genotype AD44 with 80 fruits per plant, while the lowest value was recorded in line AD25 with 10 fruits per plant. In a study conducted on Chile pepper populations, these values were reported to range between 28.06 g and 228.46 g (Rahevar et al., 2019). Fruit weight and the number of fruits per plant are known to vary depending on pepper type (Kanal and Balkaya, 2021; Şahin et al., 2022).

Among the morphological observation criteria, plant growth habit was evaluated for the 90 DH lines. It was determined that 26 lines had an open growth habit, 40 lines had a closed habit, and 24 lines exhibited a semi-open structure. Regarding leaf shape, 50 genotypes had deltoid-shaped leaves, 20 lines had lanceolate leaves, and 20 lines had oval-shaped leaves. Differences in plant growth habit and leaf shape have also been reported in pepper populations (Binbir and Baş, 2010; Datta and Das, 2013; Duruk and Pınar, 2023). In terms of leaf color, 64 lines were evaluated as green-leaved, 7 lines as having light green leaves, and 19 lines as having dark green leaves. Similarly, Roy et al. (2019) and Dilfiruz and Pınar (2022) reported that leaf color in peppers can vary depending on genotype. 43 lines were found to have an entire calyx shape, while 47 lines exhibited a serrated calyx.

Based on the fruit shape criterion, 55 lines were classified as having medium-length fruits, 18 lines as having short fruits, and 17 lines as having long fruits. Regarding fruit apex shape, 53 genotypes had blunt, 33 had pointed, and 4 had rounded fruit tips. For immature fruit color, 63 lines produced dark green, 18 lines produced light green, and 9 lines produced green fruits. When mature fruit color was evaluated, 7 lines were classified as light red, 31 lines as medium red, and 52 DH lines as dark red. In terms of general fruit shape, genotypes were grouped into pointed, slightly flattened, and strongly flattened categories. The fruit orientation was determined to be pendant. Fruit shape and size, apex form, and the color intensity of immature and mature fruits are key factors in marketing strategies and represent valuable data for future breeding studies, as well as important criteria for varietal differentiation.

Among the morphological observations, no statistically significant differences were found among the lines in terms of stem shape (cylindrical), stem color (green), hypocotyl color (purple), cotyledon leaf shape (lanceolate), anthocyanin formation (absent), flower color (white), flower orientation (pendant), fruit orientation (pendant), and peduncle cavity (absent). These findings indicate that these traits were not effective in distinguishing between genotypes.

The weights harvested from each DH line throughout the growing period were recorded, and the total yield was calculated by converting the data based on the number of plants per decare. When yield per plant and total yields were evaluated, the highest total and per-plant yields were obtained from line AD8, with 6992.2 kg/da and 2797 g/plant, respectively. The lowest yield was recorded in genotype AD25, with 1155 kg/da and 462 g/plant (Table 2). Bundela et al. (2017) reported yield per plant values ranging from 110.51 g to 241.99 g in Chile pepper groups, while Rahevar et al. (2019) found yields between 71.5 g and 840.76 g per plant in Chile-type peppers. Soares et al. (2020), in their open-field study on *Habanero*-type peppers, reported total yields ranging from 1.37 to 4.22 t/da. Khan et al. (2025) determined that yield per plant in pepper populations varied between 282.4 g and 1809.4 g, while in a study on Besni pepper populations, Şahin (2024) reported total yields ranging from 155.3 g to 795.8 g.

Several studies on the collection and morphological characterization of local pepper genotypes in Turkey have been conducted by different researchers. Keleş (2007), Binbir and Baş (2010), Karaağaç and Balkaya (2010), Bozokalfa and Eşiyok (2010), Baysal (2013), Çürük et al. (2015), Keleş et al. (2016), Başak (2019), Taş and Balkaya (2021), and Altuntaş (2021) evaluated similar morphological parameters in their studies. Başak (2019) examined 99 pointed pepper genotypes based on 48 agronomic and morphological traits according to UPOV (International Union for the Protection of New Varieties of Plants) criteria. Some of these traits — including fruit length, fruit diameter, fruit wall thickness, fruit peduncle length, peduncle thickness, stem length, plant height, leaf length-width ratio, and stem length — were identified as effective parameters for distinguishing genotypes. The researchers reported that the genotypes were grouped into 15 clusters. The most significant distinction of the present study from previous ones is that it was conducted on 90 pure lines developed using DH technology, allowing the detection of a wide range of morphological variation within a population of the same origin.

In this study, 30 plant and fruit traits, as specified in the *Materials and Methods* section, were used for the morphological characterization of the lines. Using the NTSYS computer software package, the similarities among genotypes were analyzed, and a dendrogram was constructed. According to these results, the 90 DH lines were divided into two main groups. As shown in Figure 7, there was no similarity detected between these two main groups. Group A was further divided into two subgroups, which were again separated into four sub-subgroups: *A1.1, A1.2, A2.1,* and *A2.2*. Group B consisted of two subgroups, designated as *B1.1* and *B1.2*. Based on this cluster analysis, 25% of the genotypes were classified under Group B, while 75% were grouped under Group A. Cluster analyses based on morphological traits are commonly used for heterotic grouping (Boyacı et al., 2020). The similarity matrix obtained from the analysis of morphological data can be used to determine the genetic relationship level among androgenic pure pepper lines through UPGMA clustering within the gene pool.

Morphological evaluation of plants serves not only as evidence of successful spontaneous diploidization and homozygosity but also as a valuable tool for assessing the breeding potential of newly developed lines. Similarly, Grozeva et al. (2021) obtained androgenic pure lines from Balkan-type *Kapia* peppers and performed their morphological characterization. The researchers reported that the microspore androgenesis technique could serve as a valuable source for generating variation. The results obtained for agronomic and morphological parameters demonstrated substantial variability in fruit morphology and yield-related traits among androgenic lines derived from the same genetic background. These observations align with the findings of Nowaczyk et al. (2016). The breeding potential of various androgenic pepper materials has been widely reported, with numerous studies highlighting the development of promising lines exhibiting improved fruit quality (Shrestha et al., 2011; Luitel and Kang, 2013; Nowaczyk et al., 2014)

CONCLUSION

In this study, both plant and fruit characteristics of 90 dihaploid lines were determined. Within this scope, a total of 30 morphological and yield-related parameters were evaluated to determine the variation among pure lines. Significant differences were identified among the androgenic pure lines derived from the same Hatay pepper population. This finding demonstrates the high efficiency of doubled haploidy technology in generating homozygous lines without introducing additional variation.

This research has played an important role in establishing a valuable genetic resource for future DH studies and its potential use in hybrid variety breeding. The study demonstrates that the doubled haploidy technique is an effective accelerated breeding approach for producing initial breeding material and enhancing genetic diversity for variety improvement purposes.

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FIGURES and TABLES

Figure 1. The fruits of androgenic pepper lines of Hatay (Samandağ) peppers.

Figure 2. Visual and graphical representation of the variation in plant height observed among the pure lines.

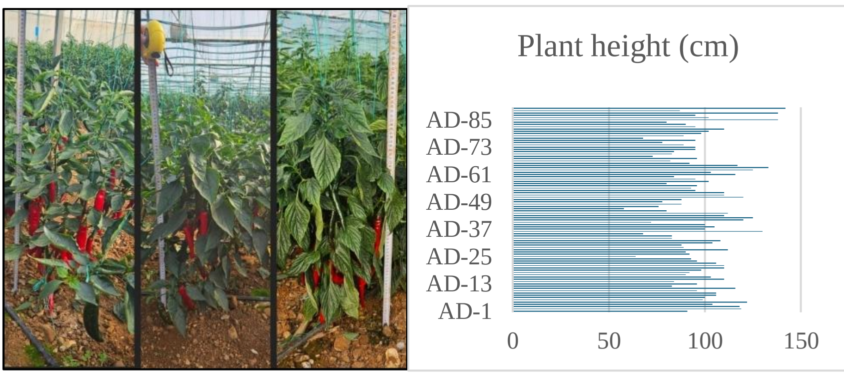
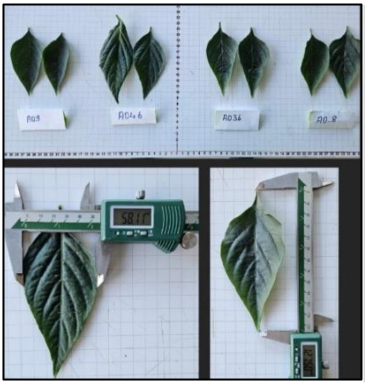


Figure 3. Visual and graphical representation of the variation in leaf index observed among the pure lines.



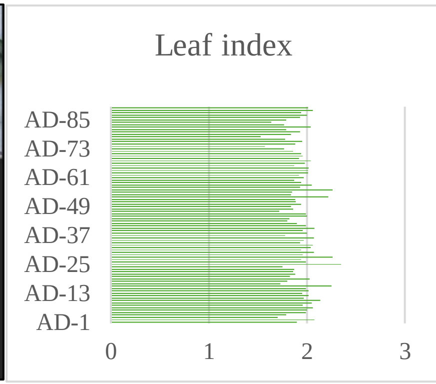
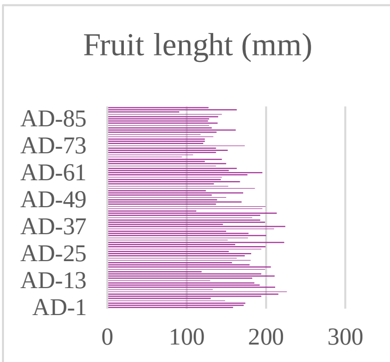


Figure 4. Graphical representation of the variation in fruit lenght and fruit index observed among the pure lines.



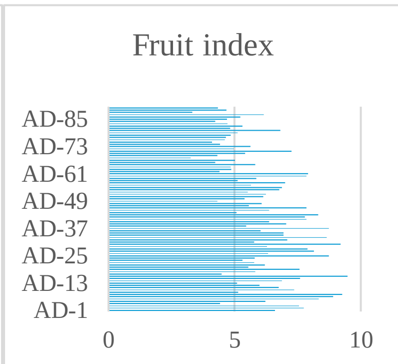


Figure 5. Fruit width, fruit length, and pericarp thickness were measured using a digital caliper.

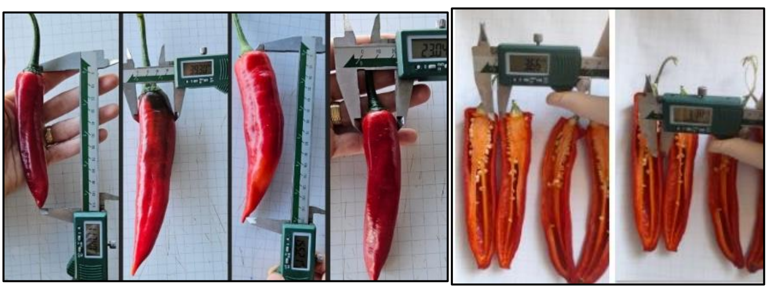


Figure 6. Longitudinal fruit sections and placenta lengths of 90 DH Hatay pepper genotypes obtained through the androgenesis method

Figure 7. Dendrogram showing the genetic distances among doubled haploid (DH) lines

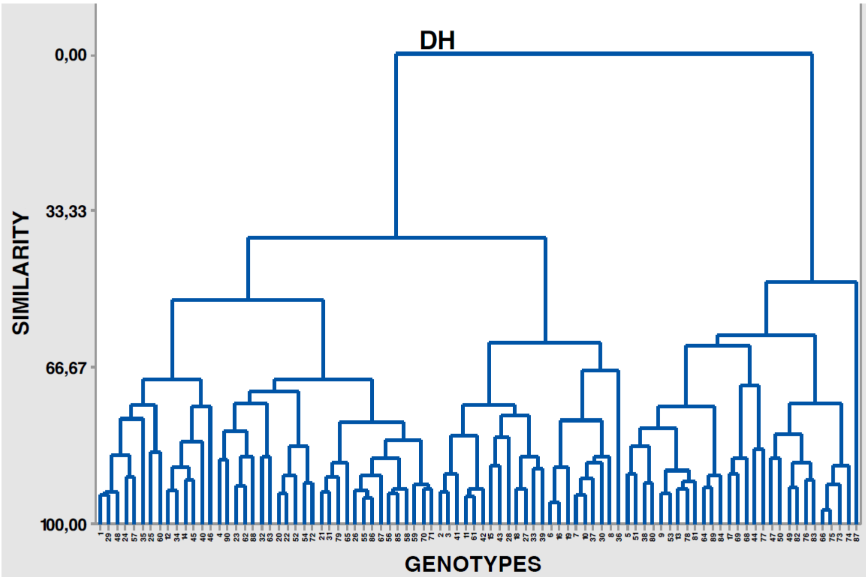


Table 1. Some of the criteria used in the characterization of 90 androgenic pepper genotypes

Morphological Traits	**Evaluation Criteria**
Stem Shape	(1) Cylindrical, (2) Angular, (3) Flattened
Stem Color	(1) Green, (2) Purple-striped Green, (3) Purple, (4) Other
Hypocotyl Color	(1) White, (2) Green, (3) Purple
Cotyledon Leaf Shape	(1) Deltoid, (2) Oval, (3) Lanceolate, (4) Long Deltoid
Flower Orientation	(1) Pendant, (3) Intermediate, (5) Upright
Flower Color	(1) White, (3) White-Purple, (5) White-Yellow
Anthocyanin Formation	(1) Present, (3) Absent
Peduncle Cavity	(1) Present, (3) Absent

Plant Growth Habit	(1) Open, (3) Closed, (5) Semi-open
Leaf Color	(1) Yellow, (2) Light Green, (3) Green, (4) Dark Green, (5) Light Purple, (6) Purple, (7) Variegated, (8) Other
Leaf Shape	(1) Deltoid, (2) Oval, (3) Lanceolate
Calyx Shape	(1) Entire, (2) Intermediate, (3) Serrated
Fruit Orientation	(1) Upright, (3) Semi-upright, (5) Pendant
Fruit Shape	(1) Medium, (2) Short, (3) Long
Fruit Apex Shape	(1) Blunt, (3) Pointed, (5) Rounded
Fruit Color (Green Stage)	(1) Green, (3) Light Green, (5) Dark Green
Fruit Color (Red Stage)	(1) Light Red, (3) Red, (5) Dark Red

Table 2. Total yields and yield per plant values in 90 androgenic DH pepper lines

DH line no	Total yield (t/da)	Yield per plant (kg/plant)	DH line no	Total yield (t/da)	Yield per plant (kg/plant)	DH line no	Total yield (t/da)	Yield per plant (kg/plant)
AD1	3895	1.558	**AD31**	4135	1.654	**AD61**	4370	1.748
AD2	4227.5	1.691	**AD32**	3077.5	1.231	**AD62**	4710	1.884
AD3	5262.5	2.105	**AD33**	3040	1.216	**AD63**	3380	1.352
AD4	4702.5	1.881	**AD34**	2665	1.066	**AD64**	2855	1.142
AD5	5530	2.212	**AD35**	3560	1.424	**AD65**	2390	9.56
AD6	4742.5	1.897	**AD36**	2580	1.032	**AD66**	3482.5	1.393
AD7	4172.5	1.669	**AD37**	4280	1.712	**AD67**	3405	1.362
AD8	6992.5	2.797	**AD38**	4060	1.624	**AD68**	2217.5	8.87
AD9	2672.5	1.069	**AD39**	2902.5	1.161	**AD69**	2340	9.36
AD10	4187.5	1.675	**AD40**	4812.5	1.925	**AD70**	2015	8.06
AD11	4152.5	1.661	**AD41**	6327.5	2.531	**AD71**	2037.5	8.15
AD12	3070	1.228	**AD42**	5052.5	2.021	**AD72**	2672.5	1.069
AD13	2760	1.104	**AD43**	5792.5	2.317	**AD73**	3042.5	1.217
AD14	3827.5	1.531	**AD44**	2977.5	1.191	**AD74**	2340	9.36
AD15	5942.5	2.377	**AD45**	3262.5	1.305	**AD75**	1270	5.08
AD16	4967.5	1.987	**AD46**	3890	1.556	**AD76**	2972.5	1.189
AD17	3052.5	1.221	**AD47**	2852.5	1.141	**AD77**	3040	1.216
AD18	4995	1.998	**AD48**	3810	1.524	**AD78**	3677.5	1.471
AD19	5162.5	2.065	**AD49**	2150	8.60	**AD79**	3647.5	1.459
AD20	4155	1.662	**AD50**	2645	1.058	**AD80**	3522.5	1.409
AD21	3747.5	1.499	**AD51**	2867.5	1.147	**AD81**	4080	1.632
AD22	2922.5	1.169	**AD52**	2605	1.042	**AD82**	2655	1.062
AD23	3807.5	1.523	**AD53**	2612.5	1.045	**AD83**	2730	1.092
AD24	1830	7.32	**AD54**	3432.5	1.373	**AD84**	2280	9.12
AD25	1155	4.62	**AD55**	2235	8.94	**AD85**	4302.5	1.721
AD26	2570	1.028	**AD56**	2255	9.02	**AD86**	2392.5	9.57
AD27	4995	1.998	**AD57**	1962.5	7.85	**AD87**	2285	9.14
AD28	4380	1.752	**AD58**	2747.5	1.099	**AD88**	3060	1.224
AD29	3312.5	1.325	**AD59**	2217.5	8.87	**AD89**	3302.5	1.321
AD30	3842.5	1.537	**AD60**	1852.5	7.41	**AD90**	3382.5	1.353

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GEÇİCİ KAPAK

Kapak tasarımı devam ediyor.