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Factors Influencing Plant Height in Lentil (*Lens culinaris* Medic.) for Mechanical Harvesting(§)

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ABSTRACT

The primary goal of agricultural activities is profitability as in every sector. A product that is economically unviable is not adopted by farmers. Profitable crop production is associated with yield and production costs. In legumes, the harvesting method plays a role in determining costs. Morphologically, the lentil plant is relatively short and does not grow upright compared to other plants, especially cereals. This affects the harvesting method and can lead to additional and significant costs. Therefore, the suitability of the lentil plant for mechanical harvesting is more important than for other plants. When varieties unsuitable for mechanical harvesting due to their short height are grown, profitability decreases, and farmers abandon production.

The experimental trials were conducted at the İkizce Research and Application Station, affiliated with the Field Crops Research Institute, during the 2020/21 and 2021/22 growing seasons. Seven different varieties were used in the trials during each growing season. Experimental materials were planted as summer and autumn sowings in both years. This study aimed to determine the characteristic(s) that most affect the suitability of the lentil plant for mechanical harvesting and its height in terms of growing season. In the combined analysis, statistically significant differences in plant height were found between year, variety, growing season, year × growing season, and growing season × variety. Furthermore, plant height was correlated with days to 50% flowering, days to maturity, yield, and first pod height.

***Keywords*:** Lentil, plant height, variety, growing season, autumn planting, summer planting

Introduction

Lentil (*Lens culinaris* Medic.), as other edible leguminous crops, is high in protein and contains vitamins and minerals that are vital for a healthy diet (Aydoğan et al, 2020; Irmak and Sözen, 2024;). Due to the feature of extended storage stability, it is crucial to prevent food wasting. According to FAO, 2025, lentil is an important element of crop rotation systems while due to its resilience to the climate change it can contribute ecosystem and biodiversity. It can boost the soil biodiversity and fertility by fixing atmospheric nitrogen into the soil, especially in soils with low nitrogen content (Gustafson, 2017).

Economic sustainability is the priority of farmers and agricultural businesses (Pannell et al. 2006; Tey et al. 2012). They can continue to cultivate the crop when it makes a profit. If the crop is profitable, it also means that it is economically sustainable. The profitability of a crop is determined by yield and cost. There are numerous factors that could affect the yield of the crop production. It is possible to divide that factors into three main categories. Which are technical

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factors (crop management practices, decision making), biological factors (insects, weeds, pests and diseases,) and environmental factors (climatic conditions, soil properties, topography, and water availability etc.) (Metcalfe and Elkins, 1980). Like other crops, many of the factors affecting lentil yield are influenced by uncontrollable climate. Compared to cereals, legumes have lower yields under the same growing conditions (Aydoğan et al., 2020; Irmak and Sözen, 2024). This is one of the most crucial factors that affect the increases in the production cost of the lentil.

An integral component of every economic activity is the inevitably arising cost structure. In general, in legume production, and specifically in lentil cultivation, the most decisive factor increasing production costs under Turkish conditions is the harvesting method. Lentil harvesting is carried out using three methods: 1. Manual harvesting; 2. Two-stage harvesting including machine harvesting, field drying, and finally threshing; 3. Machine (combine harvester) harvesting (Figure 1). Both manual and two-stage harvesting methods are performed when the plants turn from green to golden yellow (grain moisture content around 30%) (Khayrallah, 1981). In suitable fields without stones, combine harvesters are used directly when the lentils are completely dry during the harvesting and threshing process (Karadaş et al., 2018). Methodologically, manual harvesting is the method that causes the least grain loss compared to other methods (Mennad et al. 2017).

In West Asia and North Africa (WANA) countries, lentil harvesting is mostly done by hand (Nannish, 2000). However, in many countries, hand harvesting practices stand out as one of the main factors limiting the sustainability of lentil production due to increasing labour costs and difficulties in securing labour in rural areas. In Türkiye, lentil harvesting is largely carried out through mechanisation. Nevertheless, in seasons when the plants exhibit a morphological structure unsuitable for machine harvesting due to climatic conditions, producers are forced to resort to hand harvesting methods. A study conducted in Jordan revealed that hand harvesting of lentils constituted 17% of the production cost (Nannish, 2000), while in Mardin, this harvesting method accounted for 9.6% of the total cost (Karadaş et al., 2018). Ghimire et al. (2024) reported that in Nepal, the highest cost in lentil production is labour, accounting for 40.3%, followed by harvesting costs at 16.7%. A study conducted in Mexico between 2019 and 2020 revealed that the labour cost of manual harvesting and subsequent threshing accounted for an average of 40% of the total production cost (Sáenz-Reyes et al., 2022). Another study reported that variable costs constituted 76.50% of lentil production costs, with 26.04% of these variable costs being harvesting and threshing expenses (Karadaş et al., 2018). It has been determined that for lentil production to be profitable, labour and harvesting costs need to be reduced by 30.1% and 23.6%, respectively, and a 1% increase in labour costs increases total production costs by 0.42% (Ghimire et al., 2024). Although harvesting costs are relatively low in mechanized harvesting, one of the significant disadvantages of this method is grain loss. Indeed, Mennad et al. (2017) reported that grain loss rates in mechanized harvesting reached 25% in Syria and ranged from 13-23% in Balkan countries.

The most determining factor in harvesting method is plant height. Suitability for mechanical harvesting depends primarily on the plant's structure, but also on its condition at harvest time. The morphological characteristics of lentils do not support a strong, upright stem form, which creates significant difficulties in mechanical harvesting. Furthermore, lentil stalks are thin and weak (Saxena, 2009), and although stalk length is reported to vary between 15-75 cm (Malhotra et al., 1974), the plant height does not reach a level suitable for machine harvesting in most planting seasons. In addition, the widespread and prostrate growth of the above-ground parts of the plant is among the biggest obstacles to mechanized harvesting.

Kuzbakova et al. (2022) listed the factors related to plant height/first pod height as follows; (1) morphological characteristics: growth type, earliness, lateness, erect, prostrate and semi-prostrate, distribution of pods on the stem, (2) environmentally: planting time, photoperiod (long and short days), temperature, abiotic stress, (3) agronomically: planting time, planting density. In lentils, the heritability of first pod height is defined as low-moderate (h^2:0.28; h^2: 0.55) (Tabti et al., 2018; Ahmad et al., 2021). Plant height during harvest is influenced by both genetic factors and environmental conditions (Tullu et al., 2001). Abiotic stresses such as drought and heat, and disease infections significantly affect plant growth and reduce plant height (Parihar et al., 2020; Pratap et al., 2021). Furthermore, it has been reported that early abiotic stress factors (extreme temperatures and drought) further reduce the height of the first pod in lentils, while late-stage stress factors have less effect on plant height (Kuzbakova et al., 2022). Within the scope of agronomic practices, the row spacing used in planting significantly affects plant height and the height of the first pod. It has been reported that the height of the first pod increases as the row spacing decreases (Togay, 2000). Studies have shown that harvesting lentils from a height of 5 cm above the soil surface results in the least loss compared to hand harvesting, with a reduction of 10.1% in grain yield and 16.1% in straw yield (Silim et al., 1989). A harvesting height of 5 cm above the soil surface is claimed as the most appropriate level. In lentils, tall plant stature is a desirable characteristic because it allows for mechanised harvesting. Additionally, lentil straw, with its high protein content ranging from 4.2% to 7.8% (Erskine et al., 1989), is widely used in animal feeding. In many places, lentil straw is called “kes”, and its price is almost the same as the price of the grain.

The research was conducted to determine the effect of growing season (autumn and spring sowing) and selected agronomic traits on plant height in red and green lentil genotypes for mechanised harvesting.

Materials and Methods

The experimental material consisted of the following varieties: Fırat 87, Şakar, Çağıl, Tigris, Şanlıbey, Çiftçi, and Evirgen (red; autumn-sown, winter-grown lentils); Meyveci 2001, Gümrah, Karagül, Bozok, Sultan 1; and the Canadian varieties Richlea and Laird (green; summer-sown lentils). The trials were established in a randomized complete block design (RCBD) with four replications. The trials were conducted over two years, in 2021 and 2022, as autumn and summer- sown at the Gölbaşı-İkizce Research and Application Farm of the Field Crops Central Research Institute. For autumn and summer sowing, 300 and 250 seeds per square meter were used, respectively. At sowing, 12 kg da^{-1} of DAP (diammonium phosphate) fertilizer was applied in all experiments.

Autumn trials were planted on October 26, 2020 and October 12, 2021, respectively, during the 2020/21 and 2021/22 seasons. Summer trials were planted on March 10, 2021 and March 29, 2022. During the trial period, observations were made on first pod height (cm) and plant height (cm), number of days to 50% flowering and number of days to maturity (d), plot yield (g plot-1), and 1000-seed weight (g/1000 seeds). Plant height and first pod height were square root transformed. Plot yields were converted to kg da^{-1}. Plant height was subjected to variance analysis in terms of genotype, growing season, and years. Furthermore, correlations between the obtained observation values and plant height were examined. Statistical analyses were performed with the JMP 11 software. Climate data for the 2020/21 and 2021/22 growing seasons are given in Figures 2 and 3.

When climate data were examined, during the 2020/21 season autumn-sown and summer-sown plots received 190 mm and 113.4 mm of rainfall, respectively. During the following season, total rainfall was 202 mm for summer-sown plots, whereas 83 mm was recorded for autumn-sown plots. Accordingly, the amount of rainfall differs in each season while autumn-sown plots received higher rainfall in 2020/21, summer-sown plots received higher rainfall in the 2021/22 growing season.

Results

Plant height and first pod height analysis

Autumn sowing

In the 2020/21 autumn-sown season, the average plant height was 22 cm. The difference in plant height between varieties was found to be statistically significant at the 1% level. The highest plant height was 25 cm in the Fırat 87 variety, while the lowest was 18 cm in the Evirgen variety. However, during the 2021/22 season, the average plant height was determined to be 24 cm, and the differences in plant height between varieties were not statistically significant. The lowest height was 23 cm in the Tigris variety, and the highest was 25 cm in the Fırat 87, Çağıl, Şakar, and Şanlıbey varieties.

In the two-year average of autumn sowing conditions, the difference in plant height between varieties and years was found to be statistically significant at the level of 5% for varieties and 1% for years. The average plant height was 23.1 cm in autumn sowing over the experimental period (Table 1).

Summer sowing

The average plant height in the summer-sown season was 26 cm and 33.9 cm in 2021 and 2022, respectively. In both years, the highest plant heights were observed in the Canadian varieties Richlea and Laird. The difference in plant height between the varieties in the plantings carried out in the summer seasons of 2021 and 2022 was found to be statistically significant at the 1% level. The average for summer-sown over the two years was 30.2 cm. According to the combined analysis, the difference in plant height between the varieties and years was found to be statistically significant at the 1% level. The highest plant height over the two years was reached in the Laird variety with 36.5 cm (Table 2).

Overall, the varieties evaluated in 2022 exhibited a higher plant height than those evaluated in the previous year, with plant height being 29 cm greater. The average plant height was 30 cm in summer sowing conditions and 23 cm in autumn sowing conditions. Specifically, the Fırat 87 variety reached 25 cm in autumn-sown, while the Laird variety reached 33 cm in summer-sown. The differences in plant height observed for the year and growing season were statistically significant at the 1% level (Figure 4). Plant height and first pod height (cm) values according to growing season and year are shown in Figure 5.

The height of the first pod varied between 9.6–13.0 cm in autumn-sown plots and between 11.6–15.0 cm in summer-sown plots. The averages were 10.9 cm in autumn-sown and 13.6 cm in summer-sown. The highest first pod height was observed in the Şakar variety (autumn) at 14 cm, and in the Laird variety (summer) at 15.8 cm. Overall, an increase in plant height was associated with a corresponding increase in first pod height.

Morphological Observations Related to Plant Height

Correlation analysis was carried out to determine the relevance between morphological observations and plant height (Table 3). A statistically significant correlation was detected at the 1% level between plant height and 50% flowering days, days to maturity, yield, and first pod height. An insignificant but negative relationship was also found with 1000-seed weight.

Yield

Statistical analysis values for combined yield (kg/da) for two years in autumn and summer seasons are given in Table 4. The average yield for two years in autumn-sown plots was 112 kg/da, whereas it was 153 kg/da in summer. Yields in summer-sown plots were 36.6% higher than those in autumn-sown plots. The highest yield under autumn sowing was observed for the Çiftçi variety (169 kg/da), whereas under summer sowing, the highest yield was recorded for the Karagül variety (179.8 kg/da). The difference in yield between varieties and years in autumn-sown was found to be statistically significant at the 1% level. However, while the difference in yield between varieties in summer-sown was not statistically significant, the difference between years was found to be statistically significant at the 1% level.

Discussion

For mechanized harvesting of lentils, not only the height of the plant but also its upright growth habit is a priority. When analysing the study data, the plant's growth patterns were not considered in either autumn or summer planting. In autumn planting, the plant height of the genotypes varied between 18 and 25 cm. In red lentils, the average plant height after two years of autumn planting was found to be 23.1 cm. The highest height was found in the Fırat 87 variety, described as "Commando" due to its spots, in the Southeastern Anatolia Region, at 24.9 cm. A study conducted in Konya showed that when planting was done on October 10, the average plant height was 26.42 cm, while on October 20 it was 26.57 cm (Hakkoymaz and Önder, 2021). In other words, the difference in planting dates for autumn sowing did not affect plant height. Similarly, a study conducted in Southeastern Anatolia in 2014 used both red and autumn varieties, and plant height ranged from 44.3-55.0 cm, with first pod height varying between 10-24 cm (Koç and Akdeniz, 2019).

In our study, as well as in studies conducted in Konya and Ceylanpınar, although red varieties were planted as autumn sowings in October, the plant height in Ceylanpınar was found to be higher compared to autumn sowings in the Central Anatolia Region. This is because in Central Anatolia, the cold winters prevent vegetative growth and halt plant development. In contrast, winters in Southeastern Anatolia are milder than in Central Anatolia, allowing plants to continue growing and making them more suitable for mechanised harvesting. A study reported that when harvesting with a machine at a speed of 5 km/h and a cutting height of 59 mm from the ground, the losses during mechanized harvesting were statistically insignificant (Sidahmed and Jaber, 2004). From this perspective, it has been observed that in a stone-free field, where mechanised planting has been done, and a roller has been passed over it after planting, first pod height should be at least 10 cm for mechanised harvesting when the machine head touches the ground.

Moreover, in summer-sowing, green lentil genotypes were preferred. As a result, plant heights ranged from 27.0 to 36.5 cm, and the average was 30.2 cm. The difference in plant height between the varieties was found to be statistically significant at the 1% level. Compared with the autumn-sown, the average plant height was 13.4 cm taller compared to autumn sowing. It was observed that the highest height was obtained from two Canadian varieties: Richlea (35.1 cm) and Laird (36.5 cm). The Canadian varieties achieved the highest height due to their registered characteristics. Canada's geographical location plays a significant role in the climatic influence on plant morphology. Canadian varieties (registered at 60 degrees North latitude) experience longer summer days in their country of origin. When these varieties are brought to Türkiye (42 degrees North latitude), they complete their growing cycle in Türkiye with shorter daylight hours and more days. Therefore, in Türkiye, the Canadian variety fulfils its temperature/sunshine requirements over a longer period, resulting in even greater height growth.

Summerfield et al. (1985) stated that long days and high temperatures accelerate the flowering process, but genotypes show relative sensitivity to each of these factors, resulting in differences in flowering time under the same inductive environment. According to the results of our study, the plant height of other local summer varieties remained below 30 cm. According to the results of a study conducted in Yozgat by Erbaş Köse et al. (2017), the highest plant height of 41.79 cm was observed in the Local-3 population among 5 registered (Sultan 1, Meyveci 2001, Gümrah, Bozok and Karagül) and 4 local lentil varieties. It is estimated that this is due to the intensive use of imported green lentil seeds in the region. In a study conducted in Kırşehir in 2013-14, the plant height of green lentils was found to be between 18 and 21.3 cm (Sözen and Karadavut, 2017). Although the varieties used in that study were the same as some of the genotypes used in our study, it is predicted that climate and soil conditions probably affected the obtaining of different plant heights.

A correlation study between morphological characters revealed a strong and positive relationship between plant height and 50% flowering days, maturation days, yield, and first pod height. Kang et al. (2017) reported a strong correlation between first pod height and plant height with plant density. Similarly, Kuzbakov et al., (2022) reported a strong correlation (r=0.83-0.89) between the height of the first pod and plant height. A study conducted in Pakistan to determine the suitability of 36 lentil genotypes for mechanized harvesting showed a negative relationship between yield and the minimum pod height, and a highly significant correlation between the minimum pod height and plant height (Jawad et al., 2019). Plant height and first pod height are also affected by abiotic stress factors such as drought and high temperatures, as well as diseases, leading to a decrease in height (Sözen and Karadavut, 2017; Parihar et al., 2020; Pratap et al., 2021). Indeed, in the 2021/22 growing season, plant height was greater in both autumn and summer crops compared to the 2020/21 season. This is because rainfall in April and May, which are crucial months for cultivation, was higher than in the previous year.

A study indicated that early-flowering lentil genotypes yielded higher harvests, while late-flowering genotypes grew taller (Buekert et al., 2020). In our study, the number of days to 50% flowering ranged from 65-75 days for summer varieties and 195-199 days for autumn varieties. In summer varieties, the early-flowering varieties Meyveci 2001 and Sultan 1, with 65 days of flowering, had plant heights of 27.6 and 27 cm, respectively. The late-flowering varieties were Richlea and Laird, with 75 days of flowering. However, in terms of yield, the early-flowering varieties Meyveci and Sultan 1 yielded 160.5 kg/da and 155.9 kg/da, respectively; while the late-flowering varieties Richlea yielded 144.7 kg/da and Laird yielded 134.1 kg/da. Although many studies indicate that preferring to sow in autumn over summer results in at least a 50% increase in yield (Andrews, 1987; Sakar et al., 1988; Aydoğan et al., 2004), in our study, the yield recorded from summer-sowing genotypes was 36.8 kg/da higher than that obtained from autumn-sowing. This difference is attributed to bird damage observed under autumn sowing conditions.

In conclusion, it has been observed that factors affecting plant height in lentils are influenced by both the growing season and the genotype. Accordingly, the study recommend that in lentil breeding studies, selection should be based on to prioritize on medium-late maturing genotypes rather than very early or very late varieties to achieve optimal plant height development.

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Figure 1. Harvesting methods of lentil cultivation.

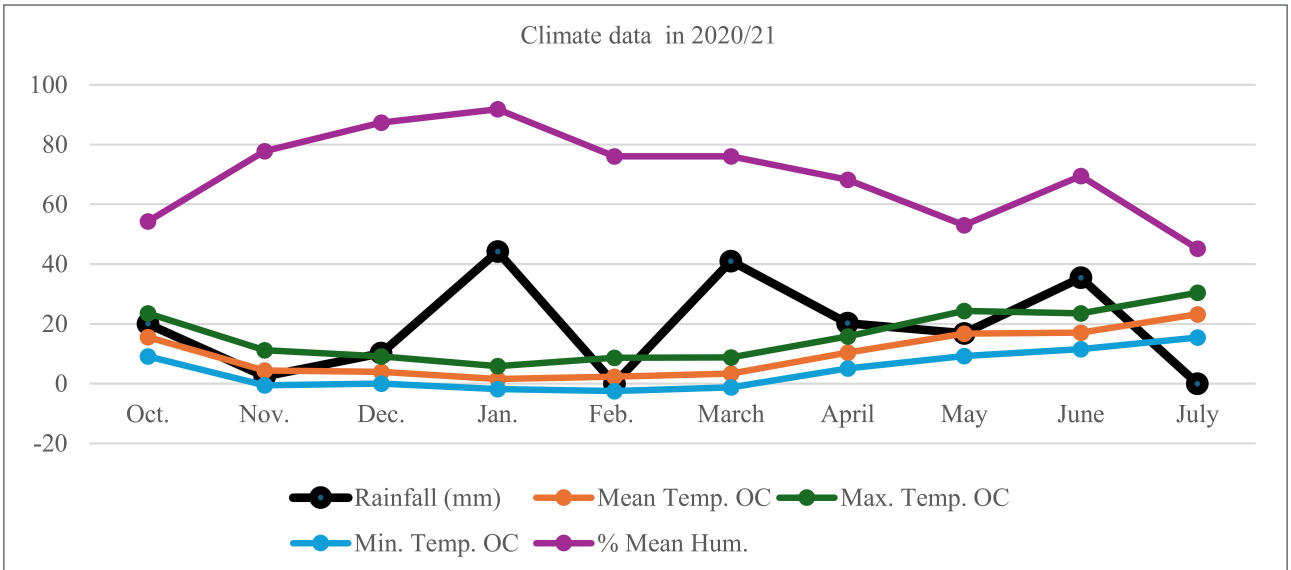


Figure 2. 2020/21 Climate data of Gölbaşı İkizce • Source: Turkish State Meteorological Service (TSMS), 2023

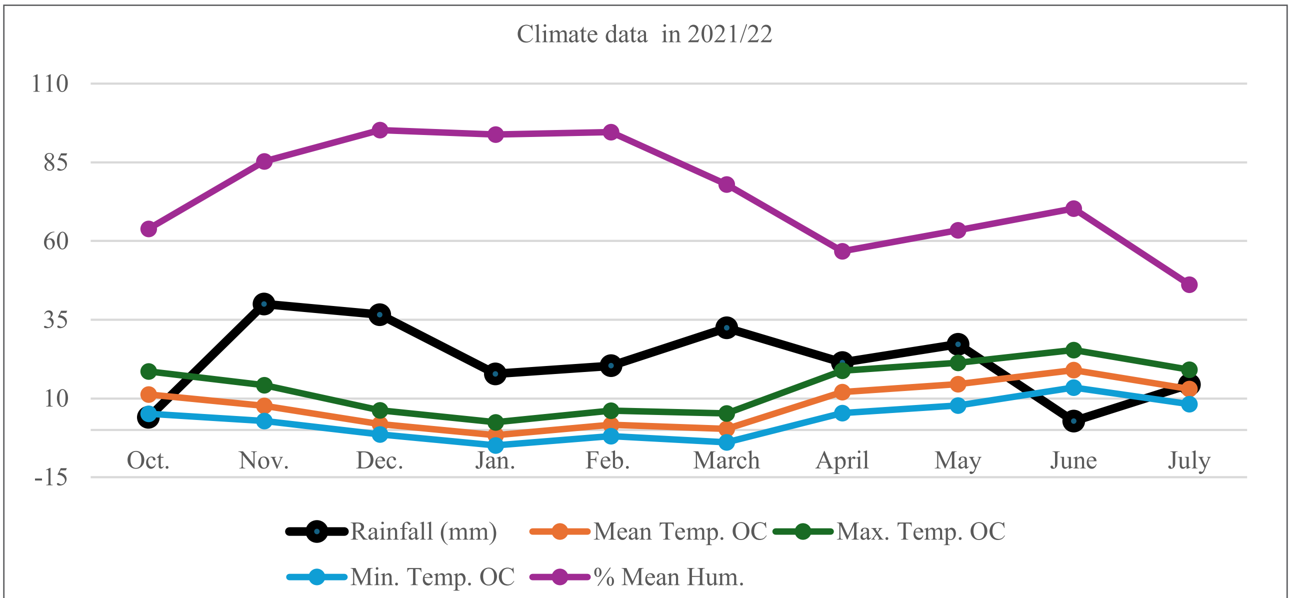
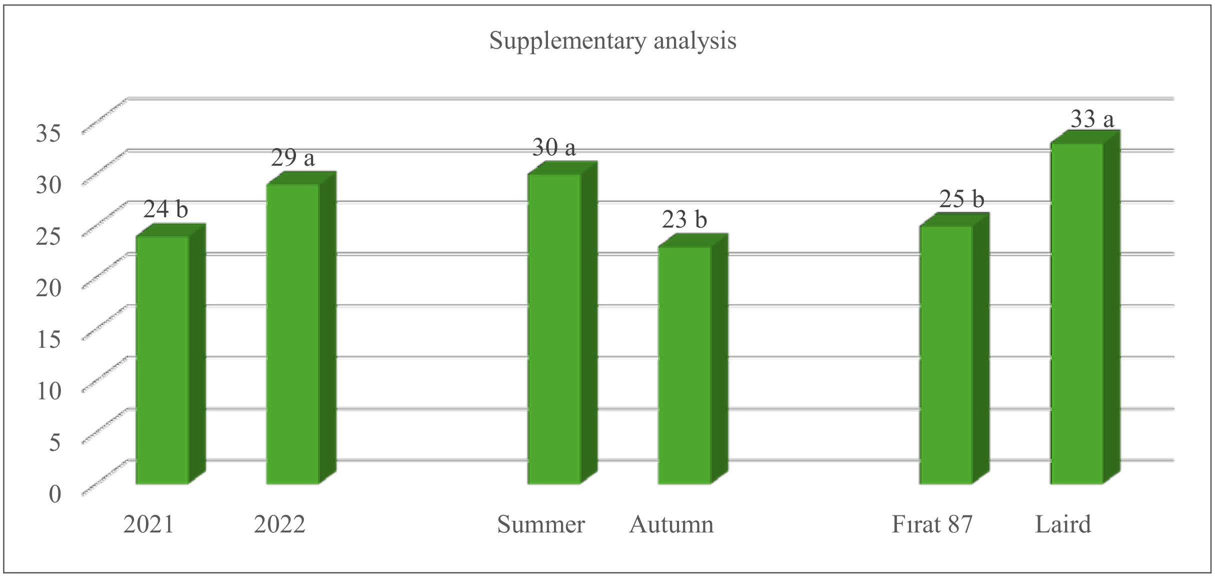
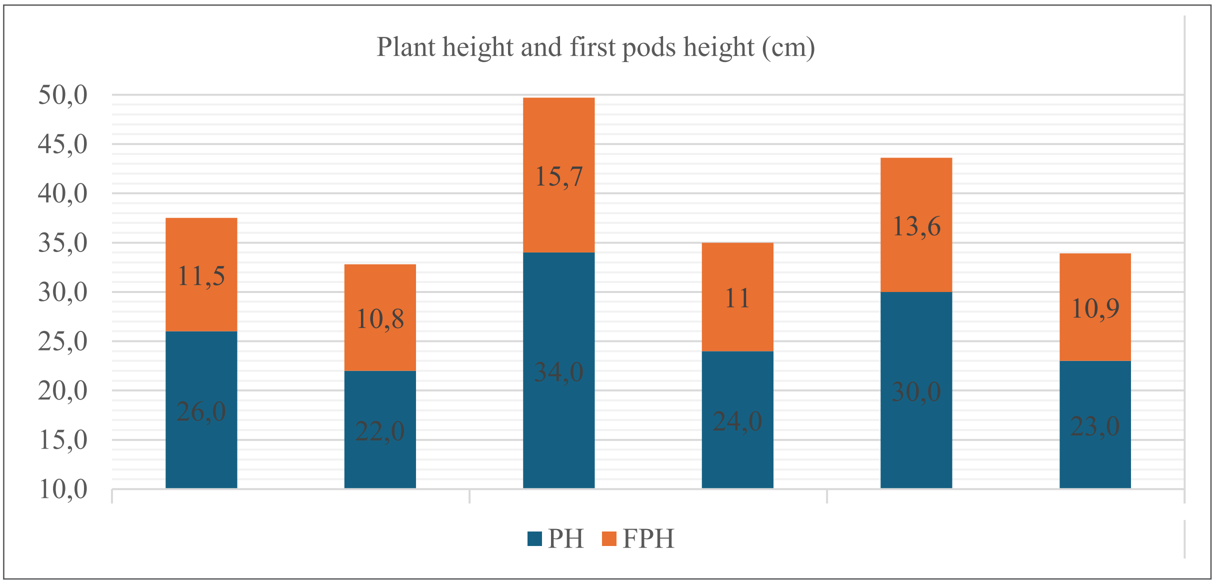


Figure 3. 2021/22 Climate data of Gölbaşı İkizce • Source: Turkish State Meteorological Service (TSMS), 2023



P(Year):**; P(Season):**; P(Season*Cultivar):*; CV (%): 7,56935

Figure 4. Plant height (cm) by year, growing season, and cultivars.



PH: Plant High; FPH: First Pod High

Figure 5. Variation in plant height and first pod height (cm) across growing seasons and years.

Table 1. Statistical analysis for plant height (cm) in Autumn sowing.

Cultivars	2020/21	2021/22	Mean of years for plant height
Fırat 87	25 a	25	24,9 a
Şakar	24 ab	25	24,4 ab
Çağıl	23 abc	25	23,9 ab
Çiftçi	22 bc	24	22,9 abc
Şanlıbey	20 cd	25	22,5 bc
Tigris	22 bc	23	22,3 bc
Evirgen	18 d	24	21,1 c
Mean	22	24	23,1
$F_{(Year)}$			18.10**
$F_{(Cultivar)}$	6.427**	0,352ns	3.12*
$F_{(Year*Cultivar)}$			2.44*
CV (%)	4.277	4,98	4,66
LSD	0,3	0,36	0,23

*:< %5; **: <%1, ns: not significant

Table 2. Statistical analysis for plant height (cm) in summer planting.

Cultivars	Years		Mean of Years for Plant Height
	2020/21	2021/22	
Meyveci 2001	23 c	32,3 b	27,6 b
Gümrah	26 bc	31,0 b	28,5 b
Karagül	24,5 bc	30,0 b	27,3 b
Bozok	25,8 bc	32,5 b	29,1 b
Sultan-1	22,0 c	32,0 b	27,0 b
Richlea	30,3 ab	40,0 a	35,1 a
Laird	33,5 a	39,5 a	36,5 a
Mean	26	33,9	30,2
$F_{(Year)}$			52,95**
$F_{(Cultivar)}$	4,42**	4,565**	8,13**
$F_{(Year*Cultivar)}$			0,75ns
CV (%)	7,42	4,98	6,47
LSD	0,56	0,48	0,36

*:< %5; **: <%1, ns: not significant

Table 3. Correlation between plant height and selected traits.

Traits	Days to 50% Flowering	Maturity duration (days)	Thousand grain weight	Yield	First pod height (cm)	Plant height (cm)
Days to 50% flowering		0.965**	−0.552**	0.320*	0.112	0.463**
Maturity duration (days)			−0.481**	0.348**	0.060	0.466**
Thousand grain weight				−0.003	−0.038	−0.067
Yield					0.192	0.533**
First pod height (cm)						0.402**
Plant height (cm)						

**p>0,01

Table 4. Combined analysis of yield values autumn- and summer-sown trials.

Autumn Sown		Summer Sown	
Cultivars	**Yield (kg/da)**	**Cultivars**	**Yield (kg/da)**
Çiftçi	169 a	Karagül	179,8 a
Şakar	136,5 b	Meyveci 2001	160,5 ab
Çağıl	133,6 b	Bozok	158,9 ab
Fırat 87	113,5 b	Sultan 1	155,9 ab
Tigris	81,1 c	Richlea	144,8 b
Şanlıbey	79,9 c	Gümrah	138,4 b
Evirgen	70,4 c	Laird	134,1 b
Mean	112,0		153,2
F (Cultivar)	14,773**	4,565**	ns
F (Year)	12,506**		46,38**
LSD (Cultivar)	27,32	4,98	34,779
CV (%)	24,05	0,48	22,39

*:< %5; **: <%1, ns: not significant

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