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EFFECTS OF DIFFERENT SOWING DATES ON PHOTOSYNTHETIC PIGMENTS AND STRESS-RELATED BIOCHEMICAL TRAITS IN COMMON BEAN (*Phaseolus vulgaris* L.)

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Abstract: The present study investigated the effects of different sowing dates on photosynthetic pigments and stress-related biochemical characteristics in the leaves of seven common bean (*Phaseolus vulgaris* L.) genotypes under the ecological conditions of Bayburt, Türkiye. Field experiments were conducted during the 2019 growing season using a randomized complete block design with three replications. Three sowing dates (7 May, 22 May, and 6 June) and seven bean genotypes were evaluated. Chlorophyll a, chlorophyll b, carotenoid, proline, malondialdehyde (MDA), and total phenolic compound contents were determined using standard spectrophotometric methods. Sowing date significantly affected chlorophyll a and carotenoid contents, whereas chlorophyll b, proline, malondialdehyde, and total phenolic compound contents were not significantly affected. The second sowing date (22 May) resulted in the highest mean chlorophyll a and chlorophyll b contents, although the effect on chlorophyll b was not statistically significant, whereas the highest carotenoid content was recorded in the earliest sowing date (7 May). Genotypic differences in the investigated biochemical traits were generally not statistically significant. These findings indicate that sowing date primarily affected selected photosynthetic pigments, particularly chlorophyll a and carotenoids, while the evaluated sowing dates did not significantly alter the measured stress-related biochemical parameters under the environmental conditions of Bayburt.

Keywords: Carotenoid, Chlorophyll, Malondialdehyde, *Phaseolus vulgaris* L., Proline, Sowing date

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1. Introduction

Common bean (*Phaseolus vulgaris* L.) is one of the most important grain legumes cultivated worldwide and represents a major source of dietary protein, carbohydrates, vitamins, minerals, and bioactive compounds for human nutrition. Owing to its high nutritional value and adaptability to diverse agroecological conditions, common bean plays a significant role in sustainable agricultural production systems as well as global food security (Adams et al., 1985; Şehirali, 1988).

Among the agronomic practices affecting bean production, sowing date is one of the most critical management factors determining plant growth, development, yield, and quality. A systematic review of common bean agronomic practices identified sowing season as an important factor affecting crop performance, while field studies have demonstrated that the response to sowing date varies with environmental conditions and season (Scarisbrick et al., 1976; Karavidas et al., 2022). Recent studies conducted under different agroecological conditions in Türkiye have also demonstrated that genotype × environment interactions substantially influence bean adaptation and productivity, emphasizing the importance of optimizing agronomic practices according to local environmental conditions (Cokkizgin, 2025; Girgel, 2026). Appropriate sowing time enables plants to encounter favorable environmental conditions throughout their growth cycle, whereas delayed or early sowing may expose plants to suboptimal temperature, solar radiation, and soil moisture conditions. These environmental fluctuations can considerably influence physiological activities, photosynthetic efficiency, and biochemical metabolism (Woolley et al., 1991). Photosynthetic pigments, including chlorophylls and carotenoids, are indispensable components of the photosynthetic apparatus. Chlorophyll pigments are directly responsible for light harvesting and energy conversion, whereas

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carotenoids function not only as accessory pigments but also as effective antioxidants protecting the photosynthetic system against photooxidative damage caused by reactive oxygen species (ROS) (Fracheboud et al., 2002; Kabay and Şensoy, 2016). Environmental stresses frequently reduce pigment synthesis or accelerate pigment degradation, thereby decreasing photosynthetic performance and plant productivity. In common bean, high-temperature stress has been shown to reduce photosynthesis and leaf photosynthetic pigments while increasing stress-related biochemical responses such as proline and MDA, demonstrating the sensitivity of these traits to environmental conditions (Chávez-Arias et al., 2018). Leaf chlorophyll status has also been reported as a reliable physiological indicator associated with biomass production and seed yield in common bean under different nutrient management systems (Girgel et al., 2023).

Plants exposed to unfavorable environmental conditions activate a series of biochemical defense mechanisms to minimize oxidative damage. One of the most common adaptive responses is the accumulation of compatible osmolytes such as proline, which contributes to osmotic adjustment, membrane stabilization, and ROS scavenging (Hare and Cress, 1997). Similarly, malondialdehyde (MDA), a final product of membrane lipid peroxidation, is widely accepted as a biochemical indicator of oxidative stress and cellular membrane damage (Türkan et al., 2005; Chávez-Arias et al., 2018). In addition, phenolic compounds constitute an important part of the antioxidant defense system because of their ability to neutralize reactive oxygen species and protect cellular structures under stress conditions (Grace, 2005; Lee et al., 2007). Recent work in common bean has likewise demonstrated that temperature stress is associated with changes in chlorophyll, carotenoids, polyphenols, MDA, and proline, reinforcing the value of these parameters as complementary indicators of physiological stress responses (Meza et al., 2025).

Although numerous studies have investigated the influence of sowing date on the agronomic performance and yield components of common bean (Akçin, 1974; Scarisbrick et al., 1976; Çiftçi and Allahverdi, 2001; Ceyhan, 2004; Karavidas et al., 2022), considerably less information is available regarding its effects on physiological and biochemical characteristics, particularly photosynthetic pigments and oxidative stress-related metabolites under the ecological conditions of northeastern Türkiye. Understanding these biochemical responses may provide valuable information for optimizing sowing schedules and improving crop adaptation under varying environmental conditions.

Therefore, the objective of the present study was to evaluate the effects of three different sowing dates on photosynthetic pigments (chlorophyll a, chlorophyll b, and carotenoids) and stress-related biochemical parameters, including proline, malondialdehyde, and total phenolic compounds, in the leaves of seven common bean genotypes grown under the ecological conditions of Bayburt, Türkiye.

2. Materials and Methods

2.1. Experimental Site

The experiment was conducted during the 2019 growing season at the Agricultural Research and Application Area of Aydıntepe Vocational School, Bayburt University, Bayburt, Türkiye (40°24′N, 40°08′E). The experimental area is characterized by a continental climate with cold winters and relatively cool, dry summers. According to the long-term meteorological records (1959–2023) obtained from the Turkish State Meteorological Service, the annual mean air temperature is 7.1 °C and the annual precipitation is 449.9 mm. During the bean growing season (June–September), the mean monthly temperatures were 15.3, 18.8, 18.9, and 14.8 °C, while the corresponding monthly precipitation values were 51.8, 21.0, 16.0, and 21.9 mm, respectively.

2.2. Plant Material and Experimental Design

Seven common bean (*Phaseolus vulgaris* L.) genotypes, namely Aydıntepe Merkez, Ala Çiftçi, Mollaköy, Konursu, Mispir, Yukarıkırzı, and Suludere, were used as plant materials.

The experiment was established according to a randomized complete block design (RCBD) with three replications. Three sowing dates were evaluated:

- E1: 7 May 2019
- E2: 22 May 2019
- E3: 6 June 2019

Each experimental plot consisted of four rows with a row spacing of 50 cm and an intra-row spacing of 10 cm. Seeds were manually sown at a depth of approximately 5–6 cm. Standard agronomic practices, including irrigation, weed control, and other cultural operations, were uniformly applied throughout the growing period.

2.3. Sampling Procedure

Leaf samples were collected from all treatments at a comparable late vegetative stage, immediately before or at the onset of flowering. Ten young, fully expanded leaves were randomly sampled from representative plants within each plot.

Immediately after sampling, leaf tissues were frozen in liquid nitrogen and stored at −80°C until biochemical analyses were performed.

2.4. Determination of Photosynthetic Pigments

Photosynthetic pigments were determined according to the methods described by Lichtenthaler (1987) and Kabbadj et al. (2017). Approximately 0.2 g of fresh leaf tissue was extracted with 90% acetone, and the absorbance of the extracts was measured spectrophotometrically at 665, 645, and 470 nm.

Chlorophyll a, chlorophyll b, and total carotenoid contents were calculated using the corresponding equations described for these pigments in the cited spectrophotometric method and expressed on a fresh weight basis (μg g^{-1} FW).

2.5. Determination of Proline Content

Free proline content was determined according to the acid-ninhydrin method described by Kabbadj et al. (2017). Fresh leaf tissues were extracted with 3% sulfosalicylic acid, and the absorbance of the reaction mixture was measured at 520 nm using a UV–visible spectrophotometer. The results were expressed as μmol g^{-1} fresh weight (FW).

2.6. Determination of Malondialdehyde (MDA)

Lipid peroxidation was estimated by measuring malondialdehyde (MDA) content following the thiobarbituric acid (TBA) method described by Kabbadj et al. (2017). Leaf tissues were homogenized in 0.1% trichloroacetic acid (TCA), and absorbance was recorded at 532 nm. MDA concentration was expressed as nmol g^{-1} fresh weight (FW).

2.7. Determination of Total Phenolic Compounds

Total phenolic compounds were determined according to Chandler and Dodds (1983). Briefly, 0.2 g of fresh leaf tissue was ground in liquid nitrogen and extracted with 5 mL of 80% methanol. After extraction, the homogenates were centrifuged, and 1.0 mL of the supernatant was mixed with distilled water, Folin–Ciocalteu reagent, and sodium carbonate. After incubation at room temperature, absorbance was measured at 725 nm. Total phenolic content was quantified using a gallic acid calibration curve and expressed as mg gallic acid equivalents (GAE) g^{-1} fresh weight (FW).

2.8. Statistical Analysis

The experimental data were subjected to analysis of variance (ANOVA) using the SAS statistical software package. Mean comparisons were performed using Duncan's Multiple Range Test at the 5% probability level. Statistical significance was declared at $P<0.05$. Degrees of freedom, F-values, P-values, and coefficients of variation (CV%) are reported in the ANOVA summary table.

3. Results

The overall analysis of variance is summarized in Table 1. Sowing date significantly affected chlorophyll a ($F=6.60$, $P=0.0033$) and carotenoid content ($F=6.16$, $P=0.0047$), whereas its effects on chlorophyll b, proline, MDA, and total phenolic compounds were not significant ($P>0.05$). Genotype and sowing date × genotype interaction effects were not significant for the investigated traits. The coefficients of variation ranged from 10.74% for total phenolics to 49.57% for proline (Table 1).

3.1. Photosynthetic Pigments

3.1.1. Chlorophyll a content

The chlorophyll a content of bean leaves was significantly influenced by sowing date ($P < 0.05$), whereas genotype and the sowing date × genotype interaction had no significant effects (Tables 1 and 2). Across all genotypes, the highest mean chlorophyll a content (255.05 μg g^{-1} FW) was recorded in the second sowing date (22 May), followed by the first sowing date (251.75 μg g^{-1} FW).

Table 1. Summary of analysis of variance (ANOVA) for the investigated biochemical traits

Trait	Effect	df	F-value	P-value	CV (%)
Chlorophyll a	Sowing date	2	6.60	0.0033	19.29
	Genotype	6	1.11	0.3734	
	Sowing date × Genotype	12	1.06	0.4207	
Chlorophyll b	Sowing date	2	2.29	0.1149	41.55
	Genotype	6	1.74	0.1371	
	Sowing date × Genotype	12	0.38	0.9641	
Carotenoid	Sowing date	2	6.16	0.0047	32.02
	Genotype	6	1.62	0.1666	
	Sowing date × Genotype	12	0.86	0.5933	
Proline	Sowing date	2	0.71	0.4996	49.57
	Genotype	6	0.32	0.9216	
	Sowing date × Genotype	12	0.65	0.7855	
MDA	Sowing date	2	0.68	0.5122	46.45
	Genotype	6	0.43	0.8529	
	Sowing date × Genotype	12	0.84	0.6096	
Total phenolics	Sowing date	2	2.04	0.1433	10.74
	Genotype	6	0.40	0.8739	
	Sowing date × Genotype	12	1.58	0.1377	

df= degrees of freedom, CV= coefficient of variation, MDA= malondialdehyde. Effects were considered significant at $P<0.05$.

Table 2. Effects of different sowing dates on chlorophyll a content in the leaves of seven common bean (Phaseolus vulgaris L.) genotypes (μg g^{-1} FW)

Genotypes	7 May	22 May	06 June	Mean
Aydıntepe Merkez	266.598	254.555	146.180	222.44[a]
Ala Çiftçi	228.980	243.668	172.307	214.98[a]
Mollaköy	241.098	282.526	255.922	259.85[a]
Konursu	247.325	210.947	243.608	233.96[a]
Mispir	245.161	265.869	204.030	238.35[a]
Yukarıkırzı	265.349	268.057	210.059	247.82[a]
Suludere	267.723	259.758	229.670	252.38[a]
Mean	251.75[a]	255.05[a]	208.83[b]	238.543

Means followed by the same letter are not significantly different according to Duncan's Multiple Range Test at P<0.05.

The lowest value (208.83 μg g^{-1} FW) was obtained from the latest sowing date (6 June). Among the genotypes, Mollaköy produced the highest overall chlorophyll a concentration (259.85 μg g^{-1} FW), whereas Ala Çiftçi exhibited the lowest mean value (214.98 μg g^{-1} FW). However, these genotypic differences were not statistically significant (Tables 1 and 2).

3.1.2. Chlorophyll b content

Chlorophyll b content was not significantly affected by sowing date (F=2.29, P=0.1149), genotype (F=1.74, P=0.1371), or the sowing date × genotype interaction (P>0.05) (Tables 1 and 3). The second sowing date produced the highest numerical mean chlorophyll b content (102.28 μg g^{-1} FW), while the lowest value (77.62 μg g^{-1} FW) was observed in the third sowing date. The first sowing date resulted in an intermediate value (89.91 μg g^{-1} FW). Although Suludere showed the highest genotype mean (112.42 μg g^{-1} FW) and Ala Çiftçi the lowest (69.90 μg g^{-1} FW), genotypic variation was statistically insignificant.

3.1.3. Carotenoid Content

Carotenoid content differed significantly among sowing dates (P<0.05) (Tables 1 and 4). Contrary to the chlorophyll pigments, the highest carotenoid concentration (1.4621 μg g^{-1} FW) was obtained from the earliest sowing date (7 May). The second and third sowing dates produced significantly lower carotenoid contents (1.0935 and 1.0991 μg g^{-1} FW, respectively), with no statistical difference between these two sowing dates. Mollaköy exhibited the highest genotype mean (1.4841 μg g^{-1} FW), whereas Aydıntepe Merkez had the lowest average carotenoid content (1.0234 μg g^{-1} FW). Nevertheless, genotype and sowing date × genotype interaction were not significant.

Table 3. Effects of different sowing dates on chlorophyll b content in the leaves of seven common bean (Phaseolus vulgaris L.) genotypes (μg g^{-1} FW)

Genotypes	7 May	22 May	06 June	Mean
Aydıntepe Merkez	93.898	95.781	47.904	79.19
Ala Çiftçi	70.501	85.942	53.255	69.90
Mollaköy	82.607	128.235	103.505	104.78
Konursu	76.010	82.023	79.253	79.10
Mispir	72.662	100.551	69.547	80.92
Yukarıkırzı	107.753	109.859	92.080	103.23
Suludere	125.948	113.535	97.789	112.42
Mean	89.91	102.28	77.62	89.937

Sowing date and genotype effects were not significant according to ANOVA (P>0.05); therefore, mean-separation letters are not presented.

Table 4. Effects of different sowing dates on carotenoid content in the leaves of seven common bean (Phaseolus vulgaris L.) genotypes (μg g^{-1} FW)

Genotypes	7 May	22 May	06 June	Mean
Aydıntepe Merkez	1.485	0.993	0.593	1.0234
Ala Çiftçi	1.402	1.015	0.913	1.1100
Mollaköy	1.383	1.578	1.492	1.4841
Konursu	1.388	0.696	1.227	1.1037
Mispir	1.363	1.152	1.071	1.1951
Yukarıkırzı	1.568	1.005	1.083	1.2186
Suludere	1.646	1.217	1.315	1.3928
Mean	1.4621[a]	1.0935[b]	1.0991[b]	1.218

Within the mean row, sowing-date means followed by the same letter are not significantly different according to Duncan's Multiple Range Test at P<0.05. Genotype mean-separation letters are not presented because the genotype effect was not significant according to ANOVA (P>0.05).

3.2. Proline Content

Leaf proline concentration was not significantly affected by sowing date, genotype, or their interaction (Tables 1 and 5). Mean proline values ranged from 1.3649 to 1.6374 μmol g^{-1} FW among sowing dates. Although the first sowing date produced numerically higher proline levels, these differences were statistically insignificant. Similarly, Suludere exhibited the highest genotype mean (1.7044 μmol g^{-1} FW), whereas Mollaköy had the lowest value (1.3479 μmol g^{-1} FW), without significant variation among genotypes.

3.3. Malondialdehyde (MDA) Content

No statistically significant differences were observed in MDA content among sowing dates or genotypes (Tables 1 and 6). Mean MDA concentrations varied between 2.0358 and 2.3736 nmol g^{-1} FW. Although the earliest sowing date showed the numerically highest MDA concentration, the differences among sowing dates were not statistically significant. Likewise, genotype means ranged from 1.9258 to 2.6070 nmol g^{-1} FW, with no statistically detectable genotype-related differences in MDA content.

3.4. Total Phenolic Compounds

Total phenolic compound content was not significantly influenced by sowing date, genotype, or their interaction (Tables 1 and 7). Mean total phenolic content ranged from 21.24 to 22.71 mg GAE g^{-1} FW across sowing dates. Genotype means ranged from 21.09 to 22.58 mg GAE g^{-1} FW, with no statistically detectable sowing-date or genotype-related differences in total phenolic content.

Table 5. Effects of different sowing dates on proline content in the leaves of seven common bean (Phaseolus vulgaris L.) genotypes (μmol g^{-1} FW).

Genotypes	7 May	22 May	06 June	Mean
Aydıntepe Merkez	1.285	1.120	1.877	1.4276[a]
Ala Çiftçi	1.325	1.926	1.266	1.5056[a]
Mollaköy	1.291	1.423	1.330	1.3479[a]
Konursu	1.281	1.640	1.217	1.3793[a]
Mispir	2.029	1.377	1.166	1.5239[a]
Yukarıkırzı	2.122	1.634	1.314	1.6898[a]
Suludere	2.129	1.600	1.384	1.7044[a]
Mean	1.6374[a]	1.5313[a]	1.3649[a]	1.5112

Means followed by the same letter are not significantly different according to Duncan's Multiple Range Test at P<0.05.

Table 6. Effects of different sowing dates on malondialdehyde (MDA) content in the leaves of seven common bean (Phaseolus vulgaris L.) genotypes (nmol g^{-1} FW)

Genotypes	7 May	22 May	06 June	Mean
Aydıntepe Merkez	2.215	2.796	1.670	2.2271[a]
Ala Çiftçi	2.107	1.706	2.409	2.0740[a]
Mollaköy	1.978	1.577	2.222	1.9258[a]
Konursu	1.777	1.936	2.287	1.9999[a]
Mispir	2.473	2.043	1.986	2.1671[a]
Yukarıkırzı	2.258	2.437	1.806	2.1672[a]
Suludere	3.806	1.756	2.258	2.6070[a]
Mean	2.3736[a]	2.0358[a]	2.0912[a]	2.1669

Means followed by the same letter are not significantly different according to Duncan's Multiple Range Test at P<0.05.

Table 7. Effects of different sowing dates on total phenolic compound content in the leaves of seven common bean (Phaseolus vulgaris L.) genotypes (mg GAE g^{-1} FW)

Genotypes	7 May	22 May	06 June	Mean
Aydıntepe Merkez	23.647	22.846	20.141	22.211[a]
Ala Çiftçi	21.132	21.097	23.221	21.817[a]
Mollaköy	20.433	19.210	23.629	21.700[a]
Konursu	19.577	21.531	23.993	21.091[a]
Mispir	21.813	22.967	22.954	22.578[a]
Yukarıkırzı	23.025	21.901	22.181	22.369[a]
Suludere	19.083	23.434	22.826	21.781[a]
Mean	21.2442[a]	21.8552[a]	22.7064[a]	21.935

Means followed by the same letter are not significantly different according to Duncan's Multiple Range Test at P<0.05.

4. Discussion

The present study demonstrated that sowing date significantly influenced chlorophyll a and carotenoid accumulation (Tables 1, 2, and 4) in common bean leaves, whereas chlorophyll b and the measured stress-related biochemical parameters were not significantly affected under the environmental conditions of Bayburt. Among the evaluated sowing dates, the second sowing date (22 May) produced the highest numerical chlorophyll a and chlorophyll b contents, while the highest carotenoid content was recorded in the earliest sowing date (7 May). However, only the effects on chlorophyll a and carotenoid content were statistically significant. These findings indicate that the response of photosynthetic pigments to sowing date was pigment-specific rather than uniform across all measured pigments.

Chlorophyll concentration is considered an important physiological indicator of photosynthetic performance and plant health. Environmental conditions such as temperature, light intensity, and soil moisture strongly influence chlorophyll biosynthesis and degradation. The higher chlorophyll a concentration observed under the second sowing date may indicate that the environmental conditions experienced during vegetative development were relatively favorable for chlorophyll accumulation. However, the absence of a statistically significant sowing-date effect on chlorophyll b indicates that not all components of the photosynthetic pigment system responded similarly. High-temperature experiments in common bean have similarly shown that photosynthetic pigments can decline under thermal stress, demonstrating the sensitivity of the photosynthetic apparatus to environmental conditions (Chávez-Arias et al., 2018).

Unlike chlorophyll b, carotenoid content was significantly affected by sowing date (Tables 1 and 4) and reached its maximum value in the earliest sowing date. Carotenoids serve both as accessory light-harvesting pigments and as important antioxidants protecting chloroplasts against photooxidative damage. Their higher accumulation during early sowing may reflect differences in the environmental conditions encountered during plant development. Common bean responses to thermal stress likewise involve changes in chlorophyll and carotenoid contents, supporting the interpretation of photosynthetic pigments as environmentally responsive traits (Chávez-Arias et al., 2018; Meza et al., 2025).

In contrast, proline, malondialdehyde (MDA), and total phenolic compound contents were not significantly affected by sowing date (Tables 1, 5–7). Proline accumulation is generally associated with osmotic adjustment under drought, salinity, and temperature stress (Hare and Cress, 1997; Arteaga et al., 2020; Kusvuran and Dasgan, 2017; Chávez-Arias et al., 2018). Likewise, MDA is widely recognized as a biochemical marker of membrane lipid peroxidation resulting from oxidative stress (Türkan et al., 2005; Nagesh Babu and Devaraj, 2008; Kusvuran and Dasgan, 2017; Chávez-Arias et al., 2018), while phenolic compounds constitute an important component of the antioxidant defense system (Grace, 2005; Lee et al., 2007; Gaafar et al., 2020). The absence of significant differences in these parameters indicates that the environmental variation associated with the three sowing dates did not produce detectable changes in these biochemical indicators under the conditions of the experiment. This interpretation should be restricted to the specific environmental conditions and sampling period of the present study.

Another noteworthy finding was the lack of significant genotype and sowing date × genotype interaction effects for the investigated biochemical traits (Table 1). This suggests that the seven bean genotypes exhibited broadly comparable physiological responses to changes in sowing time under the ecological conditions of Bayburt. However, previous work has shown that common bean responses to temperature stress can be genotype-dependent, indicating that the absence of significant genotype effects in the present experiment should not be interpreted as evidence that genotype is universally unimportant under stress (Chávez-Arias et al., 2018; Meza et al., 2025). Rather, it may reflect the environmental range and stress intensity encountered during the present field experiment.

Overall, the present findings indicate that optimization of sowing date primarily influenced selected photosynthetic pigments rather than the measured stress-related biochemical parameters. Consequently, selecting an appropriate sowing date may improve photosynthetic performance under the local environmental conditions, but the present results should not be interpreted as evidence of a universal optimum sowing date. This interpretation is consistent with broader common bean literature showing that sowing season and environmental conditions can substantially influence crop performance (Scarisbrick et al., 1976; Karavidas et al., 2022).

An important limitation of the present study is that the experiment was conducted at a single location and during a single growing season. Therefore, the observed responses should be interpreted within the environmental conditions of Bayburt and the 2019 growing season rather than generalized to all common bean production environments. Year-to-year variation in temperature, precipitation, soil moisture, and other environmental factors may modify physiological and biochemical responses to sowing date. Multi-year and multi-location experiments are therefore required to validate the present findings and evaluate the stability of sowing-date effects across contrasting environments. Common bean phenology and crop performance are strongly influenced by thermal accumulation, season, and sowing date, further supporting the need for environmental validation of these responses (Scarisbrick et al., 1976; Cavalcante et al., 2020).

5. Conclusion

The present study demonstrated that sowing date significantly influenced chlorophyll a and carotenoid contents in common bean leaves under the ecological conditions of Bayburt, Türkiye, whereas chlorophyll b, proline, malondialdehyde, and total phenolic compound contents were not significantly affected. The second sowing date (22 May) resulted in the highest numerical chlorophyll a and chlorophyll b contents, while carotenoid accumulation was greatest in the earliest sowing date (7 May). Neither genotype nor the sowing date × genotype interaction significantly influenced the investigated biochemical parameters. These findings suggest that the physiological response to sowing date was mainly reflected in selected photosynthetic pigments rather than in the measured stress-related biochemical indicators.

These findings suggest that appropriate sowing time may affect selected photosynthetic pigments without causing detectable changes in the measured stress-related biochemical parameters under the environmental conditions of the study area. Therefore, selecting an optimum sowing date should be validated through multi-year and multi-location experiments before broader recommendations are made.

Future research should evaluate a wider range of sowing dates under contrasting environmental conditions and include additional physiological and biochemical indicators to better understand the adaptive mechanisms governing stress tolerance in common bean.

Author Contributions

The percentages of the authors' contributions are presented below. All authors reviewed and approved the final version of the manuscript.

	U.G.	G.C.
C	60	40
D	60	40
S	60	40
DCP	60	40
DAI	60	40
L	60	40
W	60	40
CR	60	40
SR	60	40
PM	100	
FA	100	

C= concept, D= design, S= supervision, DCP= data collection and/or processing, DAI= data analysis and/or interpretation, L= literature search, W= writing, CR= critical review, SR= submission and revision, PM= project management, FA= funding acquisition.

Conflict of Interest

The authors declared that there is no conflict of interest.

Ethical Consideration

Ethics committee approval was not required because the study did not involve humans or animals.

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