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Effect of Cluster Drop Intensity on Nut Traits, Biochemical Properties, and Fatty Acids Composition in the 'Çakıldak' Hazelnut Cultivar

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Abstract
This study was conducted to determine the effect of cluster drop intensity (CDI) on nut traits, biochemical properties, and fatty acids composition in the 'Çakıldak' hazelnut cultivar. Many nut traits, biochemical properties, and fatty acids composition were affected by CDI. Depending on the increase in CDI, nut weight, kernel weight, nut size, kernel size, total phenolic, total flavonoids, and antioxidant activity increased. Nut weight, kernel weight, and kernel ratio were determined from 2.00 (low) to 2.31 g (high), 1.09 (low and intermediate) to 1.25 g (high), and 53.34 (intermediate) to 54.27 (low), respectively. The highest total phenolics, total flavonoids, and antioxidant activity (3675 mg per 100 g, 37.3 mg per 100 g, and 5.14 mmol per 100 g, respectively) were detected in high CDI, while the lowest (1947 mg per 100 g, 17.5 mg per 100 g, and 2.01 mmol per 100 g, respectively) were determined in low CDI. The effects of CDI on fatty acids composition were different. Oleic acid ranged from 82.46 (low) to 84.06% (intermediate), while linoleic acid was determined between 6.77 (high) and 8.78% (low). According to principal component analysis, many of the traits investigated were associated with high CDI, except nut length, kernel length, oleic acid, and linoleic acid. In conclusion, it was determined that bioactive compounds and fatty acids composition are significantly affected depending on CDI. Also, the findings of this study showed the potential consequences of the coming hazards of global warming on hazelnuts and will be helpful for future studies.

Keywords Corylus avellana · Kernel · Phenolic · Antioxidant · Oleic

Introduction

Hazelnut (*Corylus avellana* L.), an important nut species, is grown on approximately 1 million hectares in 38 countries. Türkiye is the largest hazelnut producer and exporter in the world. In Türkiye, 665 thousand tons of hazelnuts are produced on 760 thousand hectares. Italy (140,560), the USA (64,410), Azerbaijan (49,465), Chile (33,939) and Georgia (32,700) are other important hazelnut-producing countries (FAO 2022). In Türkiye, hazelnut is widely grown in the Black Sea Region, which has suitable ecological conditions (Karadeniz et al. 2009). In that region, 'Tombul', 'Çakıldak', and 'Palaz' cultivars with high commercial value are the most critical cultivars used in hazelnut cultivation. Among them, 'Çakıldak' is the most important cultivar widely used to establish new hazelnut orchards in recent years in Türkiye, the world's most crucial hazelnut producer.

Hazelnut plays a vital role in human nutrition and health thanks to its phenolics, fat and fatty acids, protein, carbohydrates, dietary fiber, vitamins, and minerals (Balta et al.

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2006; Di Nunzio 2019). Hazelnut kernel is consumed as natural (unprocessed) and roasted (Schlörmann et al. 2015). Also, it is used to flavor chocolate, bakery, candy, and confectionery products (Silvestri et al. 2021).

Hazelnut, enjoyed and consumed by people, is a nuts species rich in phenolics and antioxidants. These compounds in hazelnut play a significant role in promoting human health and reducing disease risk (Yılmaz et al. 2019; Karaosmanoglu and Ustun 2021). Hazelnut is especially effective in reducing the risk of chronic diseases such as cardiovascular, inflammatory, and neurodegenerative disorders as well as colon cancer and type 2 diabetes (Contini et al. 2011; Di Nunzio 2019). Due to these effects, the hazelnut has been suggested for the human diet (Fraser 2000).

Hazelnut is an essential source of oil and rich in unsaturated fatty acids (oleic, linoleic, palmitic, linolenic, and stearic) necessary for human health. Hazelnut kernel contains between 50 and 73% oil (Awad and Bradford 2005; Contini et al. 2011). Hazelnut benefits human health because it increases the ratio of large/small low-density lipoprotein (LDL) and reduces sensitivity to the oxidation of low LDL due to its monounsaturated and polyunsaturated fatty acids. Also, hazelnut oil positively minimizes the risk of heart disease and the adverse effects of hypertension. These benefits are associated with the fatty acid composition of hazelnut oil (Yücesan et al. 2010).

Hazelnut chemical composition is affected by various factors, such as genetic structure, cultivar, ecological condition, cultural practice (irrigation, fertilization etc.), and harvesting period (Balta et al. 2006; Pycia et al. 2020). In hazelnut, Kul (2020) reported that eco-graphical regions affect bioactive compounds. Balık (2021) suggested that the fatty acids composition and bioactive compounds vary depending on the cultivar. In addition, Tonkaz et al. (2019) and Bostan (2020) reported that irrigation significantly affected the bioactive compounds and fatty acids composition. Irrigation directly affects the hazelnut's yield and nut traits (Tonkaz and Bostan 2010; Külahcilar et al. 2018).

In the region where the research was conducted, hazelnut cultivation is performed on sloped lands without irrigation and the plant water requirement is provided by precipitations. In hazelnut cultivation, high yield and quality products depend on regular and sufficient precipitation. A significant cluster drop occurs if the plant's water requirements are not provided, adversely affecting yield and quality (Tonkaz and Bostan 2010; Külahcilar et al. 2018). Cluster drop in hazelnut is a phenomenon that continues from nut set to ripening (Stösser 2002) and is affected by many factors (ecological factors, cultivars, source of pollen, incompatibility, cultural practice, disease, and pests, etc.) (Bignami et al. 2011; Külahcılar et al. 2018).

On bioactive compounds and fatty acids composition of the 'Çakıldak' cultivar used as material in the study, many studies have been conducted to determine the effects of factors such as genetic structure, geographical origin, cultural practice, harvest time, drying methods, and storage (Turan and Islam 2018; Tonkaz et al. 2019; Kul 2020; Campa et al. 2021). However, no studies have been carried out on the 'Çakıldak' cultivar to determine the effect on these properties of cluster drop, which negatively affects yield and quality. This study aimed to determine how cluster drop intensity (CDI) affected nut traits, bioactive compounds, and fatty acid composition in the 'Çakıldak' hazelnut cultivar.

Materials and Methods

Plant Materials

The study was conducted in Ordu province, located in the Eastern Black Sea Region of Türkiye, in 2019 and 2020. The study material consisted of the 'Çakıldak' hazelnut cultivar grown in a hazelnut orchard (40°54′38.6″N latitude, 37°48′19.3″E longitude, 245 m altitude) belonging to a producer. The trial orchard was established according to the 'Ocak' (multi-stemmed bush) training system and planted at 5-m spacing in the row and 6-m spacing between rows. Except for irrigation, other standard cultural practices (pruning, fertilization, diseases, pest, and weed control) were regularly performed. During the study, chemical control was carried out against the diseases and pests of nut weevil, green shield bug, and powdery mildew. Branch thinning was carried out in the winter period, and suckering was carried out twice in the vegetation period. A total of 250 g $NH_4H_2PO_4$, 100 g K_2SO_4, and 500 g N were supplied per 'Ocak'. In addition, foliar fertilizer was applied twice a year. There were no symptoms of nutrient deficiency in the leaf or fruit during the growing season.

The research area's annual temperature and precipitation data are shown in Figs. 1 and 2 (TSMS 2022).

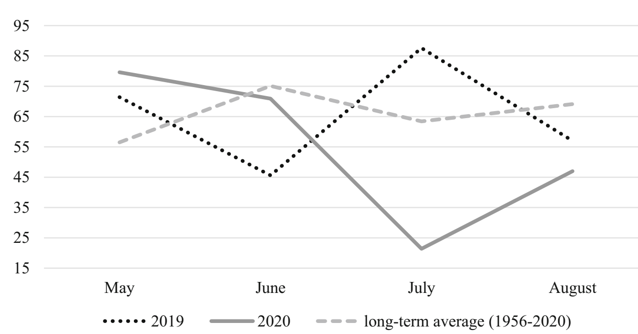

Fig. 1 Rainfall (millimeters) between May and August 2019 and 2020

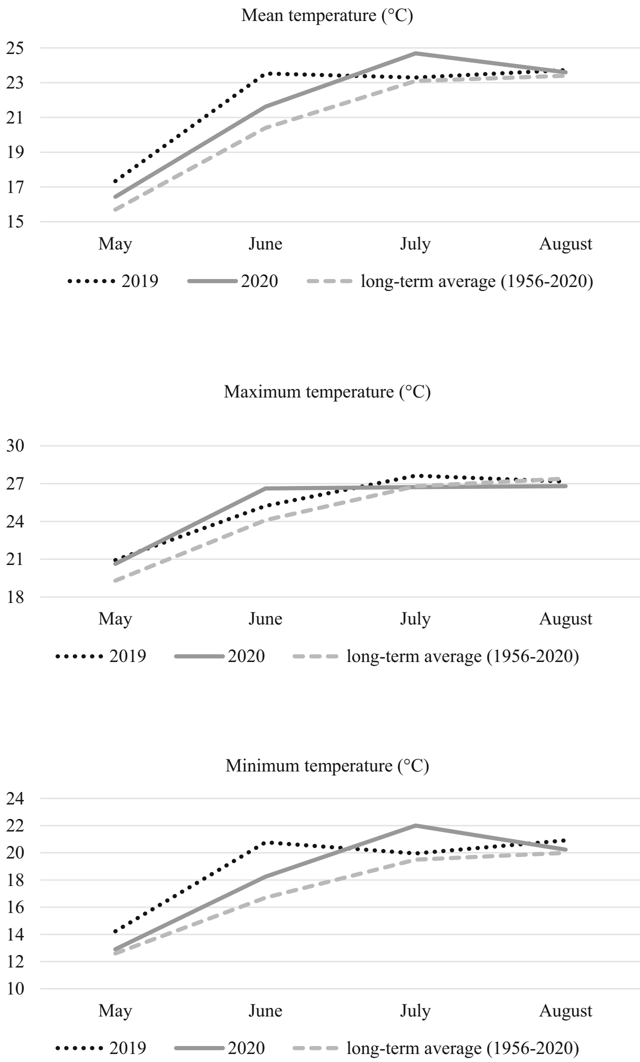

Fig. 2 Mean, maximum, and minimum temperature (°C) between May and August 2019 and 2020

Experimental Design and Cumulative Drop Ratio (%)

A total of 50 plants were marked for the 'Çakıldak' cultivar as a result of the observations made in orchards with similar characteristics and the same conditions over many years. After these plants' fruit set (at the beginning of June), cluster drops were observed at periodic intervals. To monitor this phenomenon, 15 plants were selected in three repetitions from orchards where cluster drop was seen (a total of 45 plants).

To determine the cumulative drop ratio (%) in the selected plant, the cluster number was determined four times in total, at 20-day intervals, from fruit set (beginning of June) to harvest (beginning of August), and the cumulative drop ratio (%) was calculated. Then, sampling was carried out in 15 plants with low (<10%), intermediate (10–20%), and high (>20%) drop density (Table 1) according to the classification by Milosevic and Milosevic (2012).

Table 1 Cumulative cluster drop ratio (%) of the 'Çakıldak' cultivar (2-year average)

Cluster drop intensity	6 July	26 July	15 August
Low	3.2 ± 0.58	6.5 ± 1.29	7.5 ± 1.13
Intermediate	5.5 ± 0.99	13.7 ± 3.01	17.8 ± 2.49
High	7.9 ± 1.42	21.1 ± 4.63	26.3 ± 3.68

Values are mean ± standard deviation ($n = 3$)

Nut Traits

For each treatment, nut and kernel traits were determined in 50 nuts. Nut and kernel weight (g) were determined by using electronic scales (Radwag, Poland). Kernel ratio (%) was calculated by dividing the nut weight by kernel weight. Shell thickness, nut, and kernel dimension (length, thickness, and width in millimeters) were measured with a digital caliper (Mitutoyo, Japan) (Guler and Balta 2020).

Biochemical Properties

Biochemical properties were determined in defatted hazelnut samples. Total phenolic, total flavonoids, and antioxidant activity (according to ferric reducing ability of plasma [FRAP] assay) were detected as biochemical properties. All measurements were made using a spectrophotometer (Shimadzu, Japan).

Total phenolics were determined using the Folin-Ciocalteu reagent according to the method reported by Yılmaz et al. (2019). Total flavonoids were detected according to the method reported by Chang et al. (2002). Total phenolics and flavonoids were expressed as mg GAE (gallic acid equivalent) per 100 g and mg QE (quercetin acid equivalent) per 100 g, respectively. Antioxidant activity was measured using the FRAP assay per the method described by Benzie and Strain (1996) and expressed as mmol TE (torolox equivalent) per 100 g.

Fatty Acids Composition

The fatty acids composition of oils obtained from hazelnut kernel was determined by gas chromatography (GC) according to the method reported by Karakaya (2022). GC (Shimadzu, Kyoto, Japan) was equipped with a flame ionization detector, and the capillary column (0.25 mm × 0.2 µm, 60 m, Teknokroma TR-CN100, Spain) was used to determine the fatty acids composition of hazelnut oils. Obtained oils were derivatized using potassium methylate and sulfuric acid. Then, samples extracted were injected into a capillary column. The column temperature was set at

140 °C, then raised to 240 °C. Nitrogen was used as the carrier gas (30 mL min^{-1}). The injector and detector temperatures were 250 °C. The injection volume was 1 mL. Fatty acid peaks were identified by comparing the retention time of the standard (fatty acid methyl esters) (Supelco, Merck, Germany). The results were expressed as percentages of the relative peak area of fatty acids.

Atherogenic and Thrombogenic Indexes

Atherogenic (AI) and thrombogenic (TI) indices of hazelnut kernel oil were calculated using the following formulas (Ulbricht and Southgate 1991):

$$\mathrm{AI} = \frac{\mathrm{C12:0} + 4 \times \mathrm{C14:0} + \mathrm{C16:0}}{\sum \mathrm{MUFA} + \sum \mathrm{FA\omega6} + \sum \mathrm{FA\omega3}}$$

$$\mathrm{TI} = \frac{\mathrm{C14:0} + \mathrm{C16:0} + \mathrm{C18:0}}{(0.5 \times \sum \mathrm{MUFA}) + (0.5 \times \sum \mathrm{FA\omega6}) + (3 \times \sum \mathrm{FA\omega3})}$$

Statistical Analysis

Obtained data were analyzed using JMP 14.0 (trial) software. Differences among the traits examined were determined using the LSD multiple-comparison test at $p < 0.05$. Principle component and biplot analyses were performed using the sample's nut traits, biochemical properties, and fatty acids composition.

Results and Discussion

Nut Traits

Nut and kernel weight, kernel ratio, and shell thickness are important quality traits in the hazelnut industry, as well as in the marketing and confectionery industry (Balta et al. 2018). CDI significantly affected kernel weight, but not nut weight, kernel ratio, or shell thickness ($p < 0.05$). The highest nut and kernel weight (2.31 and 1.25 g, respectively) were determined in high CDI, while the lowest was detected in low CDI (2.00 and 1.09 g, respectively). The highest kernel ratio (54.27%) was determined in low CDI. Intermediate CDI had the thinnest shell thickness (0.88 mm) (Table 2). Milosevic and Milosevic (2012) reported that in 'Tonda Gentile Romana', 'Nocchione', and 'Istarski Duguljasti' hazelnut cultivars, as CDI increased, the nut weight, kernel weight, kernel ratio, and shell thickness increased. However, they stated that the increase was not statistically significant. Similarly, Karakaya (2022) noted that in 'Tombul', 'Palaz', and 'Kalınkara' cultivars, the nut weight, kernel weight, and kernel ratio increased as CDI increased.

Table 2 Nut weight, kernel weight, kernel ratio, and shell thickness depend on intensity of cluster drop in the 'Çakıldak' hazelnut cultivar

Cluster drop intensity	Nut weight (g)	Kernel weight (g)	Kernel ratio (%)	Shell thickness (mm)
Low	2.00 a	1.09 b	54.27 a	0.95 a
Intermediate	2.05 a	1.09 b	53.34 a	0.88 a
High	2.31 a	1.25 a	54.24 a	0.96 a
Significance	ns	*	ns	ns
LSD (0.05)	0.31	0.12	2.96	0.09

The differences between mean values shown on the same line with the same letter is not significant ($p < 0.05$)
ns not significant
* significant at $p < 0.05$

Also, in the 'Çakıldak' hazelnut cultivar, Ozdemir and Akinci (2004) reported a 1.60-g nut weight, 0.93-g kernel weight, and 58.13% kernel ratio. Serdar and Demir (2005) recorded a 1.40-g nut weight, 0.76-g kernel weight, 49.30% kernel ratio, and 0.80-mm shell thickness. Balık et al. (2016) reported nut weight as 2.08 g, kernel weight as 1.18 g, kernel ratio as 55.80%, and shell thickness as 0.84 mm. Results obtained in terms of nut weight, kernel weight, kernel ratio, and shell thickness were similar to those reported by Balık et al. (2016). However, nut and kernel weight values were higher than the findings reported by other researchers. Researchers reported that ecological condition and cultural practices affected nut and kernel weight, kernel ratio, and shell thickness in hazelnut (Bak and Karadeniz 2021; Balta et al. 2021).

Depending on CDI, significant differences were determined among the other dimensional traits, except nut length, kernel thickness, and kernel length. The highest nut and kernel size (18.52 and 14.26 mm, respectively) were measured in high CDI, while the lowest was determined in low CDI (17.44 and 13.37 mm, respectively) (Table 3). In all cluster drop intensities, kernel size was over 13.0 mm. This value was suitable for marketing (Ozdemir and Akinci 2004). In the present study, nut and kernel size increased as the CDI increased. Milosevic and Milosevic (2012) and Karakaya (2022) reported similar results depending on CDI in the different hazelnut cultivars grown in Italy and Türkiye. Also, in the 'Çakıldak' cultivar, nut and kernel sizes were determined as 17.58 and 13.82 mm by Balık et al. (2016), while Ozdemir and Akinci (2004) reported these as 16.95 to 12.45 mm, respectively. The results obtained in terms of nut and kernel size were similar to those noted by Balık et al. (2016), while they were higher than the findings of Ozdemir and Akinci (2004). Differences observed could be due to ecological conditions and cultural practices.

Table 3 Nut and kernel dimensions depend on intensity of cluster drop in the ‘Çakıldak’ hazelnut cultivar

Cluster drop intensity	Nut width (mm)	Nut thickness (mm)	Nut length (mm)	Nut size (mm)	Kernel width (mm)	Kernel thickness (mm)	Kernel length (mm)	Kernel size (mm)
Low	16.68 c	15.75 b	20.21 a	17.44 b	12.50 b	11.99 a	15.96 a	13.37 b
Intermediate	17.51 b	16.25 ab	20.61 a	18.03 ab	12.82 b	11.64 a	16.09 a	13.38 b
High	18.26 a	17.01 a	20.46 a	18.52 a	14.12 a	12.82 a	16.01 a	14.26 a
Significance	**	*	ns	*	**	ns	ns	*
LSD (0.05)	0.72	0.91	1.34	0.84	0.47	1.20	1.22	0.62

The differences between mean values shown on the same line with the same letter is not significant ($p < 0.05$)
ns not significant
* significant at $p < 0.05$, ** significant at $p < 0.01$

Bioactive Compounds

Phenolic compounds with antioxidant properties promote human health and protect against many diseases associated with oxidative damage. Phenolic compounds have anti-inflammatory, anti-allergic, anti-ulcer, anti-cancerogenic, antithrombotic, and anti-atherogenic properties (Contini et al. 2011). It has been reported that total phenolics, total flavonoids, and antioxidant activity in hazelnut are affected by many factors such as cultivar, ecological condition, cultural practice, harvest time, altitude, and direction (Cristofori et al. 2015; Tonkaz et al. 2019; Yılmaz et al. 2019; Sahin et al. 2022).

Depending on CDI, there are significant differences in terms of total phenolics and total flavonoids ($p < 0.05$). In all CDIs, the highest total phenolics and flavonoids were determined in high CDI, and the lowest were detected in low CDI. As the CDI increased, total phenolics and flavonoids increased. Total phenolics were determined between 1947 (low) and 3675 (high) mg per 100 g, while total flavonoids were detected from 17.5 (low) to 37.3 (high) mg per 100 g (Table 4). Similarly, Karakaya (2022) reported that the highest total phenolics and flavonoids were determined in high CDI in ‘Tombul’, ‘Palaz’, and ‘Kalınkara’ hazelnut cultivars, and as the CDI increased, total phenolics and total flavonoids significantly increased. Othmani et al. (2020) recorded higher total phenolics in the fruit of plants with high fruit drop intensity in date palm. Also, Yılmaz et al. (2019) reported that total phenolics were determined from 662 to 763 mg per 100 g, while total flavonoids were detected from 5.4 to 11.5 mg per 100 g in the kernel of the ‘Çakıldak’ hazelnut. Pelvan et al. (2012) recorded that in the ‘Çakıldak’ hazelnut cultivar’s kernel had 246 mg per 100 g total phenolics. Kul (2020) determined that the kernel of this cultivar had 489–621 mg per 100 g total phenolics and 45.2–49.4 mg per 100 g total flavonoids. Balık (2021) reported that in the ‘Çakıldak’ cultivar’s kernel, 741 mg per 100 g total phenolics and 12.69 mg per 100 g total flavonoids were found. Although the total phenolic values obtained were higher than the researchers’ findings, the total flavonoid values were similar. In hazelnut, total phenolics and flavonoids were reported to be affected by ecological condition, maturity level, cultural practice, as well as biotic and abiotic stress factors (Cristofori et al. 2015; Yılmaz et al. 2019).

The CDI significantly affected antioxidant activity ($p < 0.05$). As the CDI increased, antioxidant activity increased. Depending on CDI, antioxidant activity ranged from 2.01 (low) to 5.14 (high) mmol per 100 g (Table 4). Similarly, it was reported that as the CDI increased, antioxidant activity increased, and high CDI had the highest value (Karakaya 2022). Also, Othmani et al. (2020) recorded higher antioxidant activity in the fruit of plants with high fruit drop intensity in date palm. According to the FRAP assay, Yılmaz et al. (2019) reported that antioxidant activity was determined from 3.35 to 5.88 mmol per 100 g in the ‘Çakıldak’ cultivar, while Kul (2020) detected between 1.12 and 1.52 mmol per 100 g. Also, Balık (2021)

Table 4 Phenolics, flavonoids, and antioxidant activity depending on intensity of cluster drop in the ‘Çakıldak’ hazelnut cultivar

Cluster drop intensity	Total phenolics (mg per 100 g)	Total flavonoids (mg per 100 g)	Antioxidant activity (mmol per 100 g)
Low	1947 c	17.5 c	2.01 c
Intermediate	2783 b	22.0 b	3.55 b
High	3675 a	37.3 a	5.14 a
Significance	***	***	***
LSD (0.05)	71.8	4.16	0.50

The differences between mean values shown on the same line with the same letter is not significant ($p < 0.05$)
*** significant at $p < 0.001$

reported antioxidant activity as 1.95 mmol per 100 g in the 'Çakıldak' cultivar's kernel. Findings obtained in terms of antioxidant activity were similar to those of Yılmaz et al. (2019), whereas it was higher than the results of other researchers. It has been reported that the antioxidant activity of hazelnut kernel can be affected by various factors such as ecological condition, cultural practice, maturity level, and various stress factors (pathogenic attack, drought, low and high temperature, etc.) (Cristofori et al. 2015; Tonkaz et al. 2019; Ozdemir et al. 2022).

Although secondary metabolites in plants vary depending on genetic structure, environmental factors such as temperature, light, and precipitation significantly affect them (Appel and Hirt 2004). Shahi et al. (2020) reported that drought stress increased bioactive compounds in hazelnut. In the present study, it was recorded that during nut development (between May and August) of the studied cultivars, the temperature values were higher (mean 2.5 °C) than the long-term average, and the precipitation values were lower (about 39%) (Figs. 1 and 2). This situation led to the high phenolic and antioxidant accumulation in plants having a high CDI and being exposed to drought stress.

Fatty Acids Composition

Hazelnut plays a significant role in human nutrition and health because of its fatty acids, especially oleic and linoleic acid composition. Hazelnut with a high oil content is rich in unsaturated fatty acids (Balta et al. 2006; Contini et al. 2011). Oleic is the major fatty acid in hazelnut and ranges from 64 to 86% depending on the cultivar (Balık 2021). Linoleic, palmitic, and stearic are other important fatty acids. Thanks to its fatty acids, hazelnut plays a significant role in lowering the cholesterol level in the blood and reducing the risk of heart disease (Yücesan et al. 2010).

Depending on the CDI, significant differences were determined among the fatty acids composition, except for oleic and palmitoleic acid. The highest palmitic and stearic acid were found in high CDI, while the highest linoleic acid was determined in low CDI. Depending on CDI, fatty acids composition ranged from 6.55 to 7.13% for palmitic acid, from 2.13 to 2.38% for stearic acid, from 82.46 to 84.06% for oleic acid, from 6.77 to 8.78% for linoleic acid, and as 0.08 for palmitoleic acid (Table 5). Results showed that CDI had a different effect on the fatty acids composition. Similarly, Karakaya (2022) reported that CDI significantly affected the fatty acids composition of the 'Tombul', 'Palaz', and 'Kalınkara' hazelnut cultivars and that the kernel contained higher oleic and stearic acid and lower linoleic acid in plants with low CDI.

Also, Alasalvar et al. (2010) recorded that 'Çakıldak' hazelnut kernel oil contains 5.02% palmitic acid, 2.44% stearic acid, 80.99% oleic acid, 10.63% linoleic acid, and 0.14% palmitoleic acid. Göncüoğlu-Taş and Gökmen (2015) reported that 'Çakıldak' hazelnut oil contains 4.59% palmitic acid, 4.61% stearic acid, 83.1% oleic acid, and 6.39% linoleic acid. Balık (2021) determined that this cultivar's oil contains 7.46% palmitic acid, 4.89% stearic acid, 80.03% oleic acid, 7.40% linoleic acid, and 0.23% palmitoleic acid. The fatty acid composition values obtained are generally consistent with findings reported by researchers.

While CDI significantly affected saturated fatty acid (SFA) and polyunsaturated fatty acid (PUFA), monounsaturated fatty acid (MUFA) was not affected ($p < 0.05$). The highest SFA was found in high CDI, while the highest PUFA was determined in low CDI. SFA, PUFA, and MUFA values were determined from 8.68 to 9.52%, 7.09 to 8.78%, and 82.54 to 84.14%, respectively (Table 5). SFA, PUFA and MUFA values were determined as 9.40%, 13.80%, and 76.90%, respectively, in the 'Çakıldak' cultivar's oil by Ozdemir et al. (2001). Alasalvar et al. (2010) recorded that 'Çakıldak' hazelnut oil contains 7.67% SFA, 10.63% PUFA, and 81.29% MUFA. Göncüoğlu-Taş and Gökmen (2015) reported that SFA, PUFA, and MUFA were determined as 9.20%, 6.39%, and 83.1%, respectively, in the 'Çakıldak' hazelnut oil. In the 'Çakıldak' cultivar's kernel oil, Balık (2021) recorded 12.35% SFA, 7.4% PUFA, and 80.26% MUFA. In the current study, SFA, PUFA, and MUFA values significantly changed depending on CDI. Similarly, Karakaya (2022) reported that SFA, PUFA, and MUFA values were significantly affected by CDI in hazelnut.

Table 5 Fatty acids composition (%) depending on intensity of cluster drop in the 'Çakıldak' hazelnut cultivar

Cluster drop intensity	Palmitic	Stearic	Oleic	Linoleic	Palmitoleic	∑SFA	∑PUFA	∑MUFA	AI	TI
Low	6.55 b	2.13 b	82.46 a	8.78 a	0.08 a	8.68 b	8.78 a	82.54 a	0.07 b	0.19 b
Intermediate	6.45 b	2.32 a	84.06 a	7.09 b	0.08 a	8.76 b	7.09 b	84.14 a	0.07 b	0.19 b
High	7.13 a	2.38 a	83.63 a	6.77 c	0.08 a	9.52 a	6.77 c	83.71 a	0.08 a	0.21 a
Significance	**	*	ns	***	ns	*	***	ns	***	***
LSD (0.05)	0.36	0.14	1.66	0.15	0.02	0.50	0.15	1.66	0.007	0.006

The differences between mean values shown on the same line with the same letter is not significant ($p < 0.05$)
ns not significant
* significant at $p < 0.05$, ** significant at $p < 0.01$, *** significant at $p < 0.001$

CDI significantly affected the AI and TI indices. As CDI increased, AI and TI indices increased. AI was determined from 0.07 (low and intermediate) to 0.08 (high), while TI was detected from 0.19 (low and intermediate) to 0.21 (high) (Table 5). Karaosmanoğlu (2022) reported that AI changed from 0.05 to 0.06 and TI from 0.15 to 0.17 in hazelnut. The AI and TI values were higher than the findings reported by Karaosmanoğlu (2022).

Fatty acids in hazelnut, which vary depending on many factors, are affected differently by drought stress (Zhong et al. 2011; Hamrouni et al. 2001). Zhong et al. (2011) reported that the content of unsaturated fatty acids in hazelnut increased due to drought stress, while Hamrouni et al. (2001) stated that it decreased. In addition, depending on water stress, many researchers noted similar results for fatty acids in hazelnut (Bignami et al. 2011; Bostan 2020). In the present study, it was recorded that during nut development (between May and August) of the studied cultivars, the temperature values were higher (mean 2.5 °C) than the long-term average, and the precipitation values were lower (about 39%) (Figs. 1 and 2). Due to this situation, CDI significantly affected the fatty acid profile of the ‘Çakıldak’ cultivar. High palmitic and stearic acid were detected in plants with high CDI, whereas high linoleic acid was determined in plants with low CDI. The highest oleic acid was determined in the intermediate CID.

Principle Component Analysis

According to principle component analysis (PCA) results, the first two components (PC1 and PCA) explained 100% of the data. PC1 was mainly related to total phenolics, total flavonoids, antioxidant activity, palmitic acid, stearic acid, linoleic acid, palmitoleic acid, nut weight, kernel weight, nut width, nut thickness, nut size, kernel width, kernel thickness, and kernel size, and explained 68.1% of the data. PC2, which explained 31.9% of the data, was associated with oleic acid, kernel ratio, shell thickness, nut length, and kernel length. Also, low CDI was grouped by linoleic acid. In contrast, high CDI was grouped by bioactive compounds, palmitic acid, stearic acid, palmitoleic acid, nut weight, kernel weight, kernel ratio, shell thickness, nut width, nut thickness, nut size, kernel width, kernel thickness, and kernel size. The intermediate CDI was grouped by oleic acid, palmitoleic acid, nut length, and kernel length (Fig. 3).

The nut traits, bioactive compounds, and fatty acids composition properties in the PC1 and PC2 were highly correlated with each other (Fig. 3). Many researchers confirmed such a relationship in different hazelnut cultivars (Yılmaz et al. 2019; Bak and Karadeniz 2021; Karakaya 2022; Karaosmanoğlu 2022). Karakaya (2022) reported a high positive relation between nut weight and kernel weight, kernel weight and kernel ratio, total phenolics and

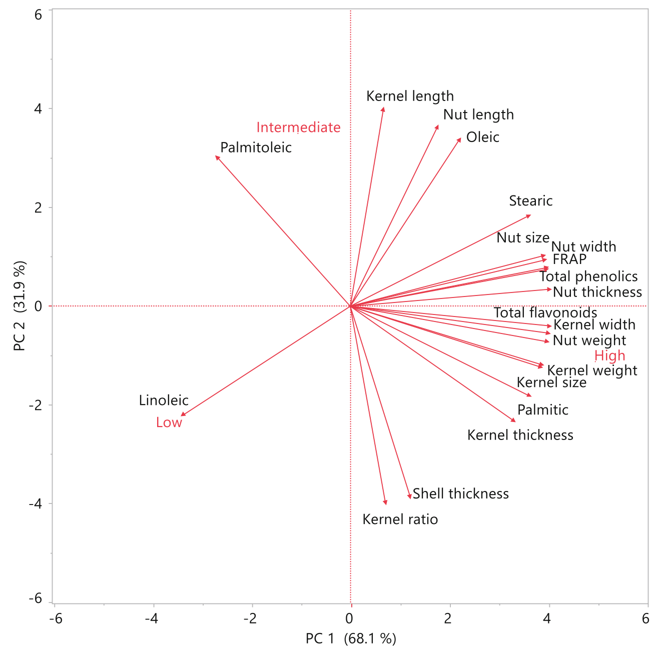

Fig. 3 Relationships amongst nut traits, bioactive compounds, and fatty acids composition in the ‘Çakıldak’ cultivar in terms of cluster drop intensity. *FRAP* ferric reducing ability of plasma

total flavonoids, total phenolics and FRAP, total flavonoids and FRAP, oleic acid and palmitic acid, arachidic acid, and palmitoleic acid in hazelnut. Karaosmanoğlu (2022) reported that fatty acids and bioactive compounds were highly correlated in organic and conventionally cultivated hazelnuts, and the first two components explained 69% of the total variation in the data.

Conclusion

In the study examining the effect of CDI on nut traits, bioactive compounds, and fatty acid composition of the ‘Çakıldak’ hazelnut cultivar, the properties investigated were significantly affected depending on CDI. With the increase in CDI, nut weight, kernel weight, nut size, kernel size, total phenolics, total flavonoids, and antioxidant activity increased, and high CDI had the highest value. Also, the fatty acids profile varied depending on CDI. The highest oleic acid and linoleic acid were determined in the intermediate and low CDI, respectively. In conclusion, CDI significantly affected the bioactive compounds and fatty acids composition that benefit human health. In addition, the findings of this study showed the possible impact of the oncoming hazards of global climate change on hazelnuts.

Author Contribution OK: investigation, methodology, formal analysis, conceptualization, writing, validation, visualization. İY: formal analysis, investigation, validation. HK: formal analysis, conceptualization, methodology. SU: investigation, formal analysis, validation. TK:

formal analysis, conceptualization, validation. MFB: methodology, investigation, writing, conceptualization, validation, review and editing.

Declarations

Conflict of interest O. Karakaya, İ. Yaman, H. Kırkaya, S. Uzun, T. Kaya, and M.F. Balta declare that they have no competing interests.

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