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Clonal Selection of 'Mincane' Hazelnut cv: Physical Properties

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Abstract

This study was conducted to identify Mincane cv clones with superior physical traits in the Trabzon province, Maçka district, Esiroğlu region between 2014 and 2019. Selection research in the study area based on the study objective revealed 14 Mincane clones with superior traits. In these selected clones, yield, number of nuts per cluster, nut characteristics, kernel characteristics, nut weight, shell thickness, kernel weight, kernel percentage, shriveled kernel, kernel cavity, blank kernel, split suture, black-tipped kernel, picola nut, lemoning, sour lemon taste, tumor ratio, good kernel, defective kernel, fibrousness, bleaching ability, perforated nut traits, and sensory and color properties were investigated. Physical traits varied greatly within the Mincane cv, and this difference was statistically significant (P<0.001). It was concluded that the G_1, G_6, G_4, and G_{11} clones were promising and that it would be useful to closely monitor the G_{13} clone.

Keywords: Genotype, nut quality, plant breeding, pomology, sensory analyses

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Mincane Fındık Çeşidinde Klon Seleksiyonu: Fiziksel Özellikler

Öz

Bu araştırma 2014-2019 yılları arasında Trabzon ili Maçka ilçesi Esiroğlu bölgesinde Mincane fındığının fiziksel özellikleri bakımından üstün klonlarını belirlemek amacıyla yürütülmüştür. Çalışmanın yürütüldüğü alanda amaca yönelik yürütülen seleksiyon çalışması sonucunda 14 adet Mincane klonu bazı özellikleri bakımından üstün bulunmuştur. Seçilen bu klonlarda verim, çotanaktaki meyve sayısı, kabuklu meyve özellikleri, iç özellikleri, meyve ağırlığı, kabuk kalınlığı, iç ağırlığı, randıman, buruşuk iç oranı, göbek boşluğu, boş iç oranı, çıtlak meyve oranı, siyah uçlu iç, pikola fındık oranı, limonlaşma, ekşi limonlu, urlu iç, dolgun iç, kusurlu iç, liflilik, beyazlama oranı, delikli meyve, duyusal analizler ve renk özellikleri incelenmiştir. Bu incelemeler sonrasında Mincane fındık çeşidi içerisinde fiziksel özellikler bakımından büyük bir varyasyon olduğu görülmüş ve bu farklılık istatistiki olarak önemli bulunmuştur (P<0.001). Çalışma sonucunda G_1, G_6, G_4 ve G_{11} klonlarının ümitvar olduğu görülmüş, ayrıca G_{13} klonunun da dikkatlice takip edilmesinin yararlı olacağı anlaşılmıştır.

Anahtar Kelimeler: Genotip, meyve kalitesi, bitki ıslahı, pomoloji, duyusal analizler

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1. Introduction

The hazelnut of the genus *Corylus*, which belongs to the birch *(Betulaceae)* family and grows as a shrub or small tree, is one of the most consumed hard-shelled fruits worldwide. Hazelnut is also one of the leading crops globally among nuts. The hazelnut has been grown in Anatolia since ancient times, and the Black Sea region of Turkey has the most suitable habitat for its cultivation. It is one of Turkey's most important export crops. The hazelnut production in Ordu, Giresun, Trabzon, Bolu, Sakarya, and Samsun, located in the Black Sea region, accounts for nearly 90% of Turkey's total. In the Black Sea region, summers are cool (23°C–24°C), winters are mild (5°C–7°C), heavy precipitation is observed, and the interior is generally characterized by a continental climate. The mountains that run parallel to the coast limit agricultural areas and influence the climate. In the Black Sea region, which has the greatest amount of rainfall in Turkey, the mountains prevent humidity from passing from the coastal areas to the interior districts, causing vegetation to differ (Öztürk and Serttaş, 2018; Turan and İslam, 2020).

Because of these climate characteristics, this region produces the world's highest quality hazelnuts. Aside from direct consumption, hazelnut is widely used in the food industry as an ingredient or as hazelnut oil. Hazelnut is a nutrient-rich food because of its high content of amino acids and fatty acids (Dönmez et al., 2016). It is important in human nutrition and health because of its composition of mono- and polyunsaturated oleic and linoleic fatty acids, sterols, essential minerals, free phenolic acids, phenolic compounds, and organic acids (Shafiei et al., 2020). In addition to being consumed as a snack, hazelnuts are widely used in the food industry as whole, chopped, or flour. In addition, the use of hazelnut oil is important in the food industry, and 80% of hazelnuts are processed in the production of chocolate; 15% in the confectionery, biscuit, and pastry industries; and 5% is consumed fresh without processing (Cansev et al., 2018).

Its antioxidants have anticancer and antiatherosclerotic properties, and phytochemicals and phenolic compounds protect against the harmful effects of cancer and oxidative stress (Yılmaz et al., 2019). The nutritional value of hazelnut varies based on cultivar, harvest season, drying method, clonal differences, nutrition, altitude, and habitat (Turan, 2018). However, it is well known that the most important factor is the genetic structure of the variety and/or clone (Turan, 2007; İslam, 2019). Many characteristics distinguish economically valuable hazelnut varieties, including the number of nuts per cluster (NPC), nut and kernel weight, efficiency, shell thickness, bleaching ability (BA), shriveled kernel ratio, and split suture ratio. However, clones with high yield and industry-oriented superior quality traits are preferred for cultivar breeding.

To make this decision, the breeder must investigate and evaluate more than one factor affecting complex traits, such as yield, which are controlled by multiple genes. Accordingly, extensive research into the physiology of traits controlled by different genes is required. Thus, in selection breeding programs, it is critical to investigate correlations between different traits and their economic importance. A positive correlation between two or more traits enables the simultaneous breeding of multiple variants, while a negative correlation indicates the need for an association between desirable traits (İşbakan and Bostan, 2020). In addition, these quantitative characteristics can be greatly affected by environmental factors. In other words, they have the potential to be far more variable than single gene traits. Therefore, breeders must be knowledgeable about the causes of yield variability in various environmental conditions. Otherwise, all the work and effort will be in vain.

Numerous selection studies have been conducted since 1969 (İslam, 2000; Turan, 2007; Turan and Beyhan, 2009; Göğüs, 2015; Pekdemir, 2019; Şahin, 2019; Kan, 2019; İslam and Çayan, 2019), and breeding selection methods are still being researched in the agricultural field. Plant mutation and natural hybridization can cause a wide range of variation within a variety. Therefore, selecting clones with desired traits among the variations is critical for breeders (İslam, 2019). Because the novel variations may have a higher economic value than the source variety or vice versa, selection breeding studies are ongoing.

Unfortunately, most selection breeding studies have been conducted and are being conducted in extremely large areas and with a large number of materials. However, field studies have revealed that specific investigations into a limited area produce more significant results. In addition, most of these studies have similar selection criteria, and there are few studies with well-defined cultivar characteristics.

Hazelnuts are one of the most popular nuts because they are not only delicious but also high in calories. They can be consumed fresh or blanched. Hazelnuts are used in bakery products, confectionery, and chocolates as well as in some high-end products, such as chopped hazelnuts and hazelnut milk (Fan et al., 2020). Hazelnut oil, which is rich in high-quality unsaturated fatty acids, is used as a cooking oil with a yellow color and flavor (Matthaus et al., 2012). Aside from it being edible, hazelnut oil can be used to make soap, cosmetics, candles, and other household items (Alaşalvar et al., 2006).

Because the shape and size of the hazelnut affect the machine configuration used in the integrated facilities, the commercial identification of the shelled and kernel hazelnut varieties to be processed is based on physical characteristics known as morphological characteristics (Turan, 2007; Hosseinpour et al., 2013; Krol et al., 2020). However, statistical analysis based on genetic and/or metabolomic markers is considered a more appropriate method for obtaining a clear definition of hazelnut cultivars, taking into account their geographical origins (Ghisoni et al., 2020).

There are 20 standard hazelnut cultivars in Turkey, and variety registration trials are ongoing. Except for newly registered varieties, all other varieties show significant variation, necessitating the continuation of selection studies. Selection of commercially produced Tombul, Foşa, and Palaz cultivars has started and is still ongoing. However, no selection studies have been conducted on the Mincane cv, which originates from Trabzon. When ongoing selection breeding studies for many years were examined, it was discovered that studies were conducted in a wide area with a large number of materials. This complicates and prolongs the selection of superior clones. With a large number of potential varieties in Turkey, a lack of completed selection studies, even in the Eastern Black Sea region, has a negative impact on the country's agricultural activities. It is critical to close this gap immediately and to conduct detailed studies in limited areas. Detailed studies in specific areas can reduce the likelihood of error ratio and material-based issues.

A comprehensive selection study was conducted in a limited area in the Trabzon province, Maçka district, Esiroğlu region. The present study aimed to select clones with superior characteristics by thoroughly examining all villages and neighborhoods around the valley. It has been concluded that the study data will lead to further research in the region and that the evaluation of the obtained clones will contribute significantly to the hazelnut industry.

2. Materials and Methods

2.1. Hazelnut samples

For the selection study, all villages in the region were examined and 14 hazelnut gardens with a size of at least 5 da that were not treated with chemical pesticides were selected (Table 1). During the selection process, technical staff from the District Directorate of Agriculture, agricultural consultants, headmen, villagers, and garden owners provided information and support. The study was conducted on three plants (branches) aged ~25 years from each orchard representing the selected hazelnut orchard. During the study period, ammonium nitrate fertilizer ($5Ca(NO_3)2NH_4NO310H_2O$, CAN %26N) was observed to be used for top dressing (~50 kg/da) once a year in the middle of March; sucker shoots and weeds were pruned twice a year; and dried and old (>%50) branches were cut with no further application. These selected orchards have been studied for 5 years in terms of yield and resistance to diseases and pests. According to TGHB (2017), hazelnut orchards with regular yields and below the required threshold value for agricultural control against diseases (*Xasthomanas coryline* and *phyllactinia guttata*) and pests (*Balaninus nucum* L., *xyleborus dispar*, bud mite, and *palemona prasina*) were selected. Those clones with disease and/or pest detected above the threshold value were excluded from the ongoing study, and the study continued on the remaining material. During the study, ~200 hazelnut orchards were examined in detail. The identification, marking, harvesting, and drying processes of the selected gardens were carried out according to Turan and

Beyhan (2009). After drying, the samples were placed in a 1 kg paper bag and refrigerated at ~5°C and 60–65% relative humidity until the measurements were taken (Bosch KDN53NW22N A, No–Frost, Germany).

Table 1. Sample codification, altitude and location of hazelnut clones

Clone code	Altitude (m)	Location (Latitude and longitude)
G1	682 m	39°52′41.38″N, 39°39′33.75″E
G2	771 m	40°52′27.50″N, 39°39′45.96″E
G3	205 m	40°52′41.59″N, 39°41′16.09″E
G4	424 m	40°52′50.04″N, 39°40′18.62″E
G5	347 m	40°51′35.00″N, 39°39′58.15″E
G6	280 m	39°51′09.71″N, 39°39′48.65″E
G7	396 m	40°55′05.18″N, 39°41′54.11″E
G8	209 m	40°52′15.97″N, 39°41′11.04″E
G9	195 m	40°52′11.11″N, 39°40′54.43″E
G10	227 m	40°52′37.24″N, 39°41′56.89″E
G11	476 m	40°51′13.89″N, 39°41′45.72″E
G12	308 m	40°52′09.49″N, 39°42′09.58″E
G13	460 m	40°53′57.43″N, 39°42′11.64″E
G14	341 m	40°52′56.87″N, 39°40′36.52″E

2.2. Physical measures: Shell and kernel traits

Yield: All three branches representing the orchard in the predetermined hazelnut orchards were harvested (~27.6% humidity), manually separated from the clusters (Turan, 2018), sun dried, and weighed on a scale with an accuracy of 0.001 g (Turan, 2021). The number of NPC was calculated by dividing the number of nuts per 100 randomly selected clusters from the harvested samples (Turan and Beyhan, 2009). The nut length, nut width, nut thickness, shape index, nut weight, kernel weight, kernel percentage, shell thickness, kernel cavity, blank nut, shriveled kernel,and good and defect kernel ratios were determined according to Turan (2019) and other traits according to Çetin et al. (2020). The color properties of the shell and kernels, including *L* (brightness), *a* (redness), and b (yellowness) values, were determined using the Hunter Lab Color Flex Ez color measurement device. Before the measurements, the device was calibrated as X: 79.05, Y: 84.02, Z: 89.03, and *L*, a, and *b* values were determined by measuring from different points (Demir, 2018; Turan, 2021). The brightness or darkness of the color is represented by *L*, and its numerical value varies between 0 and 100. The color darkens as it gets closer to 0 and brightens as it gets closer to 100. The redness or greenness value of the color is represented by *a*, and *a* indicates redness in positive values and greenness in negative values. The yellowness or blueness value is represented by *b*. Similarly, when *b* has a positive value, the yellowness of the color dominates, and when *b* has a negative value, the blueness of the color dominates. Chroma (*C*) is related to the dominant pastel or vivid tone in the color. As the numerical value of the chroma increases, the vividness of the color increases. On the contrary, as the numerical value of the chroma decreases, the pastel tone dominates the color. Hue angle ($\alpha°$) represents the angle corresponding to the dominant color of the product (Alibaş et al., 2020). Sensory analysis was performed using the hedonic scale scoring test and consisted of 11 panelists in four different sessions (Şimşek, 2004). The panelists rated the hazelnuts from different orchards on a scale of 1–5 based on color, flavor, hardness, bitterness, foreign taste/smell, and overall evaluation.

2.3. Statistical analysis

Measurements were performed in triplicate on selected clones, and descriptive statistics were performed using SPSS v. 22.0 (Armok, New York: IBM Corp.). Statistical tests were conducted using SAS–JAMP v. 10.0 (SAS Institute Inc., Cary, North Carolina, USA). The difference between the results was determined at the $P < 0.05$, $P < 0.01$ and $P < 0.001$ levels.

3. Results and Discussion

In breeding studies, yield is the most important selection criterion. First, the productive individual is selected, and then other physical and/or chemical properties are evaluated. Yield, on the contrary, causes an increase in the number of NPC, nut deformation and shrinkage, and a decrease in the shell thickness. Therefore, we believe that obtaining data that will not affect commercially standard fruit sizes would be appropriate. Otherwise, because branch thinning, which is widely used for other fruits, cannot be used for hazelnut clusters, the picola hazelnut ratio will increase and the standard value will deteriorate because of nut shrinkage. In our study, the highest yield was 519.56 g for the G_1 clone, and the lowest yield was 304.45 g for the G_8 clone (Table 1); the difference between them was statistically significant ($P < 0.001$).

Many factors, such as variety, nutrition, yield, habitat, and harvest season, affect nut size (Xu and Hanna, 2010; Ercişli et al., 2011; Turan, 2017; Turan and İslam, 2019). It is also known that the heritability of nut length, girth, and thickness is high (h^2 = 0.68, 0.78, and 0.89, respectively) (Yao and Mehlenbacher, 2000). A high heritability indicates that they are less affected by environmental conditions. However, yield in hazelnuts is regarded as one of the most important factors influencing nut size. In addition, physical differences are observed even among nuts in a single cluster (Turan, 2017). During high-yielding seasons, the number of NPC and efficiency increase, while nut size and shell thickness decrease. An increase in the number of NPC causes a change in the shape value of the nut. Even within a single variety, differences in the physical properties of the fruit can appear year to year.

The number of NPC has a direct impact on the size and shape of the nut, so the ideal number is four pieces per cluster. As the number of NPC increases, the size of the nuts decreases, and they exert pressure on each other, causing shape variability and/or deformation. On the contrary, a low number of NPC has an effect on fruit size and shell thickness, and ultimately, fruit standard. (Turan, 2021). Considering the abovementioned factors, all values were deemed acceptable because the number of nuts in all selected clones was 3–5 pieces per cluster.

No statistical difference was observed in or nut and kernel weight ($P > 0.05$), but the difference in other traits was significant ($P < 0.001$). This difference was considered normal as it fell within the range of values determined in previous studies. (Turan, 2007; Turan and Beyhan, 2009; Turan, 2019; Turan, 2021). Clones that were found to be above and below the standard during selection and research were excluded from the evaluation, resulting in values that fell within a certain range.

All shell and kernel shape index values were greater than one (1; Table 2). A slight upward trend has been observed. However, all of the determined values were less than 1.4, which is accepted as the index value of the Sivri cv (Köksal, 2018). Accordingly, we reported that all selected clones exhibited characteristics of round hazelnut varieties. It has been determined that the other shape index values usually have additional and general class ı traits (Table 2). Although the difference in nut and kernel weight values was statistically insignificant ($P > 0.05$), measurements ranged from 1.69 to 2.00g and from 0.90 to 1.10 g, respectively. The economic importance of the kernel nut is greater because it is the part that is processed for export and/or fresh consumption. In this regard, it was concluded that the G_{13} clone exhibited better results in terms of nut weight, especially kernel weight.

Table 2. Mean value of physical traits of Mincane (cv) hazelnut clones

	Clone code					
Parameters	G1	G2	G3	G4	G5	Sign.
Yield (g)	519.56±27.20a	435.08±13.94c	432.93±2.37c	468.03±2.59b	406.25±6.91d	***
Nuts per cluster	3.94±0.10c	3.45±0.46d	4.18±0.13bc	3.90±0.06c	4.42±0.21b	***
Nut length (mm)	19.02±0.16bcd	19.44±0.48abc	19.58±0.27ab	19.07±0.79a-d	18.86±0.26b-e	**
Nut width (mm)	16.20±0.34	16.14±0.24	15.49±1.85	16.07±0.42	15.12±1.17	ns
Nut thickness (mm)	14.50±0.03b-e	14.14±0.27b-e	14.93±0.73bc	14.62±0.45bcd	13.47±0.50e	**
Kernel length (mm)	14.69±0.27abc	14.22±0.43bcd	15.35±0.44a	13.61±0.37d	13.62±0.55d	*
Kernel width (mm)	11.58±0.63	13.02±0.59	13.34±0.29	12.68±0.65	12.30±0.23	ns
Kernel thickness (mm)	11.81±0.61bcd	11.33±0.32de	11.67±0.21cd	12.21±0.70bc	11.22±0.26def	***
Nut						
Shape index	1.24±0.02a-d	1.28±0.04abc	1.29±0.07abc	1.24±0.05a-d	1.32±0.08a	**
Geometric diameter (mm)	16.47±0.10b	16.43±0.18b	16.51±0.34b	16.48±0.25b	15.65±0.52d	***
Volume (mm^3)	2339.15±44.53b	2322.8±76.85bc	2360.05±143.96b	2344.98±106.50b	2012.39±204.12d	***
Surface area (mm^2)	852.14±10.81b	848.11±18.77bc	856.99±35.06b	853.45±25.76b	770.25±51.74d	***
Sphericity	86.59±1.04b-e	84.53±1.89cde	84.35±2.89cde	86.50±2.27b-e	83.02±3.49e	**
Kernel						
Shape index	1.26±0.08	1.17±0.07	1.23±0.03	1.09±0.03	1.16±0.03	ns
Geometric diameter (mm)	12.61±0.31	12.80±0.15	13.37±0.18	12.81±0.10	12.34±0.27	ns
Volume (mm^3)	1051.78±76.29bcd	1097.36±37.81bcd	1251.01±51.18abc	1101.61±26.18bcd	985.03±65.29d	**
Surface area (mm^2)	499.95±24.32b	514.45±11.84ab	561.40±15.37ab	515.80±26.18ab	478.60±21.23b	**

Sphericity	85.92±3.63	90.06±3.74	87.13±1.40	94.16±1.98	90.63±1.74	ns
Nut weight (g)	1.83±0.07	1.87±0.08	1.90±0.04	1.90±0.20	1.81±0.08	ns
Kernel weight (g)	0.94±0.06	0.95±0.08	1.04±0.07	1.07±0.08	1.00±0.02	ns
Kernel percentage (%)	51.25±0.03e	50.50±0.05ef	54.81±0.07d	56.44±0.02b	55.39±bc	***
Shell thickness (mm)	0.97±0.08ef	1.11±0.09bcd	1.25±0.06a	1.02±0.14c-f	1.00±0.01def	**
Kernel cavity (mm)	1.15±0.59ef	1.88±0.42abc	1.95±0.38ab	1.45±0.54b-e	1.31±0.14c-f	**
Blank ratio (%)	6.64±0.91b	3.68f±0.17g	4.47±0.69ef	2.02±0.18h	3.68±0.20fg	***
Picola nut (%)	4.15±0.47e	6.49±0.74c	1.60±0.20g	1.59±0.32g	5.40±0.20d	***
Shrivel kernel (%)	1.21±0.47cd	0.48f±0.17gh	0.92±0.20def	0.85±0.18d-g	0.80±0.20d-g	***
Weevil kernel (%)	0.90±0.23a	0.68±0.17ab	0.92±0.02a	0.32±0.03bcd	0.34±0.05bcd	**
Grey colour kernel (%)	7.39±0.69c	4.94±0.29de	4.12±0.91fgh	3.50±0.32h	4.25±0.20efg	***
Black colour kernel (%)	9.50±0.45f	18.22±0.73a	9.74±0.72ef	6.37±0.32g	5.86±0.35g	***
Tumor kernel (%)	1.8±0.23cd	1.55±0.17d	1.03±0.34e	0.85±0.36ef	0.00±0.00g	***
Fibrousness	7.67±1.15bc	8.33±1.15ab	7.67±1.15bc	5.00±0.00e	6.33±1.15d	***
Good kernel (%)	69.46±0.68g	64.53±0.77h	83.39±0.87b	85.35±0.85a	81.35±2.22c	***
Defect kernel (%)	30.54±0.68c	35.47±0.77b	16.61±0.87h	14.65±0.85ı	18.65±2.22g	***
Pellicle removal (%)	95.17±0.86cd	94.31±0.97d	91.02±0.13e	97.34±0.37ab	95.19±0.93bcd	***
Whole pellicle removal (%)	53.27±1.13g	63.17±2.05c	59.55±3.05de	74.33±0.58b	63.89±0.64c	***

Data represent the mean ± SD (n=3). Significant level; *, **, *** and “ns” mean significance at p< 0.05, 0.01, 0.001 and “not significant”, respectively, among clones.

The kernel ratio appears to be an overrated characteristic. The hazelnut market considers this trait to be equal to or even superior to variety variations. Is high efficiency a desirable trait because pricing is done with more than 50% efficiency? Or why is the Uzunmusa cv, which has the highest yield, not considered the highest quality hazelnut? The features that distinguish hazelnut varieties and make them valuable are regular yield and standard-sized nut formation. In contrast, high kernel fullness causes stress when crushing because of the reduced space between the hard shell and kernel. Therefore, an efficiency value of 50%–54% would be preferable. The belief that the hazelnut with the highest efficiency has the best quality is incorrect. The chemical composition of the hazelnut as well as the cracking and processing operations causing the least amount of damage are essential. Increased damage and/or defective kernel ratio is not preferred by the hazelnut industry because it increases the costs. In the present study, the G_{12} clone had the lowest efficiency (47.12%), and the G_6 clone had the highest efficiency (58.81%) (Table 2), with the G_{3-6} and G_{13} clones having superior values.

Table 2. (continued1)

	Clone code					
Parameters	G6	G7	G8	G9	G10	Sign.
Yield (g)	368.43±2.50g	400.85d±3.87e	304.45±3.05ı	388.55±2.28ef	381.89±3.13fg	***
Nuts per cluster	3.25±0.10d	4.85±0.34a	3.32±0.32d	3.23±0.21d	4.48±0.25ab	***
Nut length (mm)	18.90±0.26b-e	18.39±0.54de	18.18±0.23e	19.37±0.55abc	19.14±0.27abc	**
Nut width (mm)	15.89±0.38	16.55±0.57	15.47±1.05	15.89±0.67	15.85±0.63	ns
Nut thickness (mm)	14.57±0.29b-e	13.67±1.59de	13.87±0.68cde	13.73±0.63de	14.50±0.46b-e	**
Kernel length (mm)	13.95±0.47cd	13.82±0.20cd	14.14±0.48bcd	14.46±0.59a-d	15.06±0.85ab	*
Kernel width (mm)	13.18±0.14	12.29±0.02	12.85±0.50	13.23±1.06	12.00±1.00	ns
Kernel thickness (mm)	10.40±0.52f	11.51±0.51cde	11.82±0.35bcd	10.82±0.65ef	12.05±0.95bcd	***
Nut						
Shape index	1.24±0.03a-d	1.22±0.11b-e	1.24±0.06a-d	1.31±0.10ab	1.26±0.03abc	**
Geometric diameter (mm)	16.35±0.23bc	16.06±0.49bcd	15.74±0.63cd	16.16±0.34bcd	16.38±0.04bc	***
Volume (mm^3)	2291.05±95.84bcd	2173.14±196.94bcd	2047.79±240.13cd	2212.13±136.90bcd	2301.07±16.07bc	***
Surface area (mm^2)	840.33±23.36bcd	810.85±49.47bcd	779.03±61.41cd	820.79±34.01bcd	842.89±3.92bc	***
Sphericity	86.53±1.16b-e	87.45±5.17bcd	86.57±2.57be	83.51±3.96de	85.59±1.24cde	**

Kernel						
Shape index	1.18±0.07	1.16±0.01	1.15±0.01	1.20±0.03	1.25±0.09	ns
Geometric diameter (mm)	12.41±0.14	12.50±0.24	12.90±0.42	12.74±0.67	12.94±0.41	ns
Volume (mm^3)	1000.02±34.81cd	1023.80±60.29bcd	1126.82±108.37bcd	1088.58±175.15bcd	1138.38±105.70bcd	**
Surface area (mm^2)	483.56±11.25b	491.12±19.22b	523.30±33.80ab	510.80±54.28b	526.90±32.95ab	**
Sphericity	88.99±3.56	90.48±0.68	91.27±0.28	88.05±1.25	86.07±4.03	ns
Nut weight (g)	1.69±0.30	1.87±0.03	1.88±0.04	1.85±0.15	1.82±0.06	ns
Kernel weight (g)	0.97±0.07	0.94±0.12	0.97±0.06	0.90±0.21	0.93±0.05	ns
Kernel percentage (%)	58.81±0.04a	50.23±0.01ef	51.32±0.09e	48.08±0.10g	51.17±0.08e	***
Shell thickness (mm)	1.09±0.07b-e	1.15±0.04abc	1.04±0.11cde	1.18±0.03ab	1.02±0.03c-f	**
Kernel cavity (mm)	1.47±0.27b-e	1.32±0.06c-f	1.60±0.04b-e	1.59±0.35b-e	1.27±0.09def	**
Blank ratio (%)	5.59±0.33cd	5.66±0.19cd	5.13±0.37cde	5.38±0.18cde	8.26±1.53a	***
Picola nut (%)	9.43±0.50a	4.69±0.18e	7.82±0.42b	6.42±0.36c	2.69±0.47f	***
Shrivel kernel (%)	0.44±0.19gh	0.33±0.00h	1.83±0.37ab	0.72±0.18e-h	0.93±0.00de	***
Weevil kernel (%)	0.11±0.02d	0.54±0.08a-d	0.98±0.06a	1.03±0.08a	0.31±0.00bcd	**
Grey colour kernel (%)	5.04±0.19d	3.71±0.37gh	12.33±0.56b	7.14±0.31c	4.54±0.18def	***
Black colour kernel (%)	11.18±0.33cd	10.57±0.83de	11.60±0.56c	6.62±0.47g	11.66±0.65c	***
Tumor kernel (%)	2.41±0.19b	1.74±0.19cd	0.98±0.21e	1.03±0.18e	0.72±0.18ef	***
Fibrousness	7.67±1.15c	7.00±0.00cd	7.67±1.15bc	7.00±0.00cd	9.00±0.00a	***
Good kernel (%)	68.75±0.33g	75.46±0.33d	62.27±0.37ı	73.69±0.80e	72.14±0.93f	***
Defect kernel (%)	31.25±0.33c	24.54±0.33f	37.73±0.37a	26.31±0.80e	27.86±0.93d	***
Pellicle removal (%)	95.51±0.56bcd	82.73±3.32f	93.92±0.69d	80.64±1.17f	95.42±0.63bcd	***
Whole pellicle removal (%)	65.37±0.66c	57.03±1.31ef	55.20±1.65fg	58.7±1.10e	57.13±3.73ef	***

Data represent the mean ± SD (n=3). Significant level; *, **, *** and “ns” mean significance at p< 0.05, 0.01, 0.001 and “not significant”, respectively, among clones.

Table 2. (continued2)

	Clone code				
Parameters	G11	G12	G13	G14	Sign.
Yield (g)	300.63±3.44ı	346.48±3.50h	386.90±5.53ef	407.94±2.25d	***
Nuts per cluster	4.23±0.20bc	3.28±0.19d	3.43±0.12d	3.42±0.17d	***
Nut length (mm)	19.79±0.36a	19.23±0.19abc	18.84±0.39cde	18.20±0.72e	**
Nut width (mm)	17.50±0.46	15.70±0.52	17.05±0.91	16.77±0.72	ns
Nut thickness (mm)	15.25±0.31ab	14.27±0.86b-e	16.07±0.29a	14.47±0.76b-e	**
Kernel length (mm)	14.77±0.75abc	14.64±0.71abc	14.69±0.60abc	14.12±0.96bcd	*
Kernel width (mm)	12.96±0.60	12.71±0.34	13.98±1.21	12.45±0.31	ns
Kernel thickness (mm)	12.65±0.57ab	11.49±0.36cde	13.27±0.22a	11.21d±0.13ef	***
Nut					
Shape index	1.21±0.01cde	1.29±0.06abc	1.14±0.01e	1.17±0.02de	**
Geometric diameter (mm)	17.41±0.30a	16.28±0.49bcd	17.28±0.47a	16.41±0.73bc	***
Volume (mm^3)	2766.45±139.85a	2258.10±200.53bcd	2705.50±217.17a	2320.93±316.73bc	***
Surface area (mm^2)	952.83±32.28a	831.87±49.52bcd	938.51±50.59a	846.60±76.23bc	***
Sphericity	87.99±0.43abc	84.58±2.50cde	91.71±0.62a	90.11±0.94ab	**
Kernel					
Shape index	1.15±0.09	1.21±0.05	1.08±0.09	1.55±0.68	ns
Geometric diameter (mm)	13.42±0.09	12.88±0.30	13.96±0.41	13.35±0.33	ns
Volume (mm^3)	1264.88±25.71ab	1119.60±80.35bcd	1426.41±124.85a	1037.88±129.43e	**
Surface area (mm^2)	565.59±7.68ab	521.23±24.81ab	612.44±35.93a	475.34±27.16c	**
Sphericity	91.02±4.60	88.07±2.75	95.15±5.02	92.42±2.28	ns
Nut weight (g)	1.91±0.04	1.95±0.05	2.00±0.05	1.94±0.07	ns
Kernel weight (g)	0.97±0.04	0.92±0.11	1.10±0.05	1.00±0.02	ns
Kernel percentage (%)	50.74±0.05ef	47.12±0.13g	55.08±0.07cd	51.48±0.04e	***
Shell thickness (mm)	0.91±0.08f	1.14±0.12abc	1.03±0.09c-f	1.02±0.04c-f	**
Kernel cavity (mm)	1.77±0.54a-d	1.48±0.34b-e	2.35±0.32a	0.81±0.06f	**
Blank ratio (%)	4.92±0.28de	5.98±0.34bc	5.58±0.23cd	2.81±0.16gh	***
Picola nut (%)	1.59±0.27g	9.86±0.20a	7.91±0.23b	5.54±0.16d	***
Shrivel kernel (%)	1.58±0.55bc	0.76±0.18e-h	2.08±0.22a	0.36±0.16h	***
Weevil kernel (%)	0.32±0.00bcd	0.76±0.01ab	0.13±0.00cd	0.64±0.01bcd	**
Grey colour kernel (%)	5.24±0.48d	5.27±0.40d	1.69±0.23ı	13.17±0.41a	***
Black colour kernel (%)	9.05±0.48f	15.06±0.50b	2.72±0.39h	15.44±0.16b	***
Tumor kernel (%)	0.00±0.00g	2.10±0.20bc	3.37±0.60a	0.46±0.16f	***

Fibrousness	9.00±0.00a	7.00±0.00cd	9.00±0.00a	9.00±0.00a	***
Good kernel (%)	80.95±0.48c	64.78±0.34h	82.10±0.39bc	62.67±0.27ı	***
Defect kernel (%)	19.05±0.48g	35.22±0.34b	17.90±0.39gh	37.33±0.27a	***
Pellicle removal (%)	99.37±0.83a	96.86±0.48bc	94.12±1.55d	95.19±1.93bcd	***
Whole pellicle removal (%)	93.20±0.88a	53.75±1.46g	62.59±2.25cd	49.32±2.18h	***

Data represent the mean ± SD (n=3). Significant level; *, **, *** and "ns" mean significance at p< 0.05, 0.01, 0.001 and "not significant", respectively, among clones.

The average shell thickness of hazelnuts is 1 mm, with values well above 1 mm considered a thick shell. Therefore, a shell thickness of less than 1 mm is considered suitable for market use (Turan, 2021). According to our study, the shell thickness was approximately 1 mm. The G_{11} clone had the lowest value, which distinguished it from other clones. Except for the G_3 clone, which has a shell thickness of 1.25 mm, it can be concluded that the clones are at an acceptable level.

The kernel cavity is an unstable trait that varies among varieties (Turan, 2007). In addition, the size of the internal cavity differs between the nuts within a single cluster based on the size of the nuts (Turan, 2021). No clones that differed or were severely defective in terms of this nut trait were found in our study.

In studies on pistachios, harvest season, irrigation status, plant nutrition, pruning, and rootstock have all been found to be effective on split sutures (Ertürk et al., 2015). In addition, it has been stated that splitting is a trait of variety and has a low incidence in domestic varieties (Özçağıran et al., 2005). Among the other hard-shelled nuts, the heritability of this trait has been reported to be h^2=0.48 in chestnut (Nishio et al., 2014). There have only been a few studies on the splitting trait of hazelnut. However, it is known that this trait is frequently observed in some cultivars. Split sutures have been found in both filled and poorly filled hazelnuts. It has been proposed that a hazelnut's genetic structure may contain such a trait. A high ratio of this trait is undesirable because it causes an increase in the black-tipped kernel ratio in hazelnuts. Black tips on kernels have been linked to nuts with split or weak sutures (Turan, 2007; Turan, 2017), implying that an increase in the split suture ratio affects the black-tipped kernel ratio. Therefore, clones with split sutures in the orchard were excluded during the first stage of selection.

Hazelnuts with a nut size of less than 9 mm are classified as "picola" (small hazelnuts) (Fiskobirlik, 2004) and are generally not offered to the market; they are threshed and consumed as a snack. A high picola ratio is undesirable because it is unsuitable for industrial processing, leading to a cost increase. However, after bleaching, it is regarded as the class with the highest price range. Higher sale prices may be implemented because more labor is needed during the bleaching process. Moreover, it is valuable as a snack because it has superior taste properties compared to plump nuts. The lowest value was found in the G_4 and G_{11} clones (1.59%), and the highest value was detected in the G_6 (9.43%) and G_{12} clones (9.86%). It would be better not to select these two clones with the highest value. Although picola hazelnut is a popular snack, it is not preferred because of increased costs and a lower nut standard. Currently, its consumption is uncommon, but if it becomes widespread and highly preferred in the market, clones with superior picola ratios may be evaluated. Blanched hazelnuts are unavailable in the domestic market owing to their high price. Because picola hazelnuts are more expensive, it is expected that consumption will be limited among the general population.

A low shriveled kernel ratio is preferred because it reduces BA and efficiency. Besides nut size, it is generally accepted that the most important traits affecting price are the BA and market efficiency value. In addition to variety, pricing is based mainly on commercial BA and a 50% yield in hazelnut purchases. Furthermore, shriveled kernel is influenced by many factors, such as soil structure, altitude, early harvest, clonal difference, variety, and climate (Turan and Beyhan, 2009, Kalkışım et al., 2016). The highest shriveled kernel ratio was observed in the G_{13} clone (2.08%) and the lowest in the G_7 (0.33%) clone (Table 2). When other studies were examined (Turan, 2007; Turan and Beyhan, 2009; Turan, 2017; Turan, 2019; Turan, 2021), it was found that even the highest value in our study was very low compared to previous studies. It was assumed that a population with a higher shriveled kernel ratio as a nut trait had been detected.

The hazelnut worm (*Curculio nucum*) is known to be the most important pest in the hazelnut production areas worldwide (Saruhan and Tuncer, 2010; Saruhan et al., 2010). Saruhan and Şen (2016) stated that the damage caused by hazelnut worms varies according to the cultivar, and this damage varies in varieties such as Mincane (4.57%), Sivri (3.81%), Palaz (2.80%), Çakıldak (2.80%), Tombul (2.77%), and Karafındık (2.48%). Even the highest value of 1.03% (G_9) obtained in our study was well below the previous data. These data show that the search method used in the orchard selection processes at the selection stage is appropriate. In the present study, orchards that were determined to be above the threshold value were excluded in the first stage, and orchards free of agricultural pesticides were selected. As a result, it can be predicted that the selected clones are less damaged and/or resistant to hazelnut worm damage compared to the eliminated clones and other studies.

Lemoning is defined as the formation of a dark yellow color around the part of hazelnut kernels that begins to deteriorate due to oil oxidation (Fiskobirlik, 2004; Turan, 2018). Sour lemon hazelnut kernels are defined as hazelnut kernels with distorted taste, color, and odor that leave a slightly sour taste and burn the mouth due to oxidized fat (Turan, 2017). Both traits appear after an insect sucks the kernel nut, and they develop depending on the cultivar practices. The lowest lemoning and sour lemon values were observed in the G_{13} (1.69%–2.72%, respectively) clone; the highest lemoning was recorded in the G_1 clone (12.333%); and the highest sour lemon value was recorded in the G_2 clone (18.22%). The amount of oil oxidation that occurs during lemoning varies depending on the variety (Turan, 2019; Turan, 2021). Hazelnut varieties high in unsaturated fatty acids are also more sensitive to fat oxidation (Turan et al., 2022). As a result, it was observed that the G_{13} clone was superior to the others in this trait.

Because the type of "stained kernel" damage caused by the green skunk cannot be distinguished by the external appearance, the producer is free to sell these products. No effort was made to mitigate this damage. However, the impact of "stained kernel" on hazelnut exports is critical. Stained kernel damage deteriorates the taste and appearance of the product, causing problems especially during the chocolate production process and when used as nuts (Saruhan and Tuncer 2010; Turan, 2021). Therefore, low or no damage is desired. No kernel tumor damage was detected in G_5–G_{11} clones, whereas the highest value of 3.37% was recorded in the G_{13} clone.

The increase in the fiber ratio caused a decrease in the BA of hazelnut. Therefore, it is preferred that the hazelnut kernels are fiber-free or have a low fiber content (Turan, 2007). In the present study, the lowest fiber ratio was detected in G_{10}–G_{13} clones (9; fiber-free), while the highest fiber ratio was detected in the G_4 clone with the lowest score (5; moderate) (Table 2). Although Turkish hazelnut varieties vary in terms of fiber content (Turan, 2007), it is known that the Mincane hazelnut variety is generally fiber-free (Köksal, 2018).

The good kernel ratio is influenced by many features, including variety, soil characteristics, cultivar practices, and some nut defects with high heritability (Turan, 2017). Mehlenbacher et al. (1993) reported that the heritability of the good kernel ratio was h^2=0.415. This feature also varies from year to year (Turan, 2019). The highest plump kernel ratio was detected in the G_4 clone, which also has the lowest defective kernel ratio (Table 2). The lowest good kernel ratio was found in the G_8 clone (62.27%). Commercially, the highest good kernel ratio was preferred because it reduced production costs. Clones with a higher defective kernel ratio should be eliminated.

High BA is one of the main traits sought in products to be exported (Turan, 2017; Turan, 2019; Turan, 2021). It is reported that the heritability of BA, which is affected by many factors such as soil structure, habitat, and variety, is h^2 = 0.64 (Yao and Mehlenbacher, 2000). The highest BA was observed in the G_{11} clone (99.37%), and this value was higher than that of the Tombul cv (Turan, 2007). Therefore, the G_{11} clone must be evaluated and preserved. The sensory analysis and general evaluation showed that the G_6 (4.33), G_9 (4.00), and G_{14} (4.00) clones have higher scores.

The *L* value was high in clones G_1 (39.26) and G_{13} (39.30) for the nut and in clones G_{11} (40.85) and G_{12} (40.24) for the kernel (Table 3). When the chroma values of the clones were evaluated, the most vivid colors were recorded in clones G_6–G_{13} (7.22) for the nut and in clones G_3 (10.27) and G_{12} (9.94) for the kernel. Therefore, it can be concluded that these clones are brighter in color. However, it should be noted that this color change is related to post-harvest applications, especially harvest season and drying method (Turan, 2018). Hazelnuts that are harvested early and exposed to precipitation during drying lose their brightness and become dull. Harvesting should be done according to predefined criteria, and drying processes should be completely correctly and on time. On the contrary, because the selection studies are conducted in the farmer's garden, the harvesting process is tailored to the farmer. This resulted in an earlier harvest period. If these clones had been evaluated under controlled yield conditions, the possibility of overlooking the higher brightness values would have been reduced.

Table 3. Sensory analyzes and colour parameters of Mincane (cv) hazelnut clones

	Clone code									
Parameters	G1	G2	G3	G4	G5	G6	G7	G8	G9	Sign
Sensory analyzes										
Colour	2.33±0.58c	2.33±0.58c	2.00±0.00c	2.33±0.58c	3.33±0.58ab	2.33±0.58c	2.33±0.58c	2.33±0.58c	2.67±0.58bc	
Flavour	2.33±0.58de	1.67±0.58e	3.00±0.00cd	2.33±0.58de	4.00±0.00ab	4.67±0.58a	3.00±0.00cd	4.00±0.00ab	3.33±0.58bc	**
Hardness	4.00±0.58ab	3.67±0.58b	2.00±0.00c	4.33±0.58ab	4.33±0.58ab	4.67±0.58a	3.67±0.58b	4.33±0.58ab	3.67±0.58b	**
Rancidity	4.33±0.58ab	4.33±0.58ab	4.33±0.58ab	4.33±0.58ab	5.00±0.00a	4.67±0.58a	4.33±0.58ab	4.33±0.58ab	4.33±0.58ab	**
Foreign taste	2.00±0.00cd	1.67±0.58d	4.33±0.58a	2.33±0.58cd	5.00±0.00a	5.00±0.00a	4.67±0.58a	3.33±0.58b	4.33±0.58a	**
Overview	2.67±0.58cd	2.67±0.58cd	3.67±0.58ab	2.33±0.58d	3.67±0.58ab	4.33±0.58a	3.67±0.58ab	3.33±0.58bc	4.00±0.00ab	**
Colour (Shell)										
L	39.26±0.00c	39.40±0.00a	38.26±0.01n	39.36±0.01l	38.57±0.01ı	38.75±0.01h	38.41±0.01k	38.55±0.01j	38.29±0.01m	**
a	5.23±0.00h	5.19±0.01ı	5.55±0.01c	5.50±0.00d	5.41±0.02g	5.73±0.01a	5.60±0.01b	5.44±0.01f	4.83±0.01l	**
b	4.18±0.01g	4.33±0.00e	4.23±0.01f	4.42±0.01b	4.11±0.01h	4.40±0.01c	4.22±0.00f	4.00±0.01l	3.80±0.01m	**
Browness index	20.68±0.02g	20.95±0.01f	21.95±0.02c	22.36±0.01b	21.17±0.04e	22.49±0.01a	21.94±0.03c	20.92±0.01f	19.34±0.01k	**
x	0.345±0.00g	0.346±0.00f	0.347±0.00c	0.348±0.00b	0.346±0.00e	0.348±0.00a	0.347±0.00c	0.346±0.00f	0.343±0.00k	**
Chroma value	6.70±0.00h	6.76±0.00g	6.98±0.01e	7.05±0.00b	6.79±0.01f	7.22±0.01a	7.01±0.01c	6.75±0.01g	6.14±0.01l	**
Hue value	0.97±0.00gh	0.91±0.00k	1.05±0.00c	0.97±0.00h	1.06±0.00c	1.04±0.00d	1.07±0.00b	1.11±0.01a	1.00±0.01ef	**
Colour (Kernel)										
L	38.01±0.03c	38.29±0.02c	39.81±0.01c	39.32±c	38.60±0.02c	48.68±0.03a	39.58±0.21c	38.97±0.03c	39.10±0.01c	*
a	9.44±0.02a	9.15±0.02b	9.48±0.01a	8.28±0.02f	9.06±0.03bc	8.84±0.04cd	9.12±0.02b	8.41±0.04f	8.78±0.03de	**
b	3.16±0.02j	3.25±0.01ı	3.93±0.01c	3.55±0.07g	3.36±0.02h	4.54±0.03a	3.73±0.02e	3.15±0.02j	3.62±0.02f	**
Browness index	23.86±3.84	25.56±0.05	27.06±0.05	24.66±0.03	25.51±0.09	22.80±2.84	26.03±0.21	23.53±0.09	25.43±0.04	ns
x	0.354±0.00ab	0.353±0.00abc	0.356±0.00a	0.345±0.01d	0.353±0.00abc	0.349±0.00cd	0.354±0.00ab	0.350±0.00bcd	0.353±0.00abc	*
Chroma value	9.96±0.02b	9.71±0.02cde	10.27±0.02a	9.01±0.04g	9.66±0.01de	9.94±0.03bc	9.85±0.05bcd	8.98±0.02g	9.50±0.02ef	**
Hue value	2.87±0.02a	2.70±0.00b	2.27±0.00ef	2.19±0.04g	2.57±0.01c	1.77±0.00ı	2.30±0.01e	2.54±0.00c	2.29±0.02e	**

Data represent the mean ± SD (n=3). Significant level; *, **, *** and “ns” mean significance at p< 0.05, 0.01, 0.001 and “not significant”, respectively, among clones.

Table 3 (continued)

	Clone code					
Parameters	G10	G11	G12	G13	G14	Sign
Sensory analyzes						
Colour	3.33±0.58ab	2.33±0.58c	2.33±0.58c	2.33±0.58c	3.67±0.58a	*
Flavour	3.67±0.58bc	4.00±0.00ab	1.67±0.58e	3.00±0.00cd	3.33±0.58bc	***
Hardness	4.33±0.00ab	4.33±0.58ab	3.67±0.58b	4.33±0.58ab	2.67±0.58c	***
Rancidity	5.00±0.00a	4.33±0.58ab	3.67±0.58b	2.33±0.58c	4.33±0.58ab	***
Foreign taste	4.33±0.58a	2.67±0.58bc	2.33±0.58cd	1.67±0.58d	4.33±0.58a	***
Overview	3.67±0.58ab	3.33±0.58bc	2.33±0.58d	2.33±0.58d	4.00±0.00ab	***
Shell						
L	38.83±0.01f	38.87±0.00e	38.80±0.00g	39.30±0.01b	38.97±0.01d	***
a	4.89±0.01k	5.47±0.01e	5.13±0.01j	5.57±0.02c	5.19±0.01ı	***
b	4.01±0.01k	4.36±0.00d	4.05±0.00j	4.60±0.00a	4.07±0.00ı	***
Browness index	19.80±0.01j	21.84±0.02d	20.36±0.01ı	22.46±0.03a	20.44±0.01h	***
x	0.344±0.00j	0.347±0.00d	0.345±0.00ı	0.348±0.00a	0.345±0.00h	***
Chroma value	6.33±0.00k	7.00±0.01d	6.54±0.00j	7.22±0.01a	6.59±0.01ı	***
Hue value	0.93±0.01ı	0.98±0.00g	0.99±0.00f	0.92±0.00j	1.00±0.00e	***
Kernel						
L	38.34±0.02c	40.85±0.03bc	40.24±0.04c	39.70±0.00c	39.03±0.01c	*
a	9.09±0.02bc	8.52±0.58ef	9.02±0.02bcd	8.91±0.02bcd	9.01±0.01bcd	***
b	3.17±0.02j	3.75±0.04e	4.19±0.01b	3.81±0.02d	3.55±0.01g	***
Browness index	25.19±0.10	24.26±0.97	26.70±0.04	25.81±0.07	25.66±0.02	ns
x	0.353±0.00abc	0.352±0.00abc	0.355±0.00a	0.354±0.00ab	0.354±0.00abc	*
Chroma value	9.63±0.03de	9.31±0.53f	9.94±0.01bc	9.69±0.02de	9.68±0.01de	***

Data represent the mean ± SD (n=3). Significant level; *, **, *** and “ns” mean significance at p< 0.05, 0.01, 0.001 and “not significant”, respectively, among clones.

4. Conclusions and Recommendations

The study is the first selection study in the literature to investigate the physical traits of the Mincane cv in detail. It is also the first academic study of hazelnuts in this region. The study found a statistically significant difference among clones ($P < 0.001$). There were significant differences in traits among clones, including yield in G_1 (519.56 g/plant), efficiency in G_6 (58.81%), shell thickness in G_{11} (0.91 mm), low picola hazelnut ratio in G_4–G_{11} (1.59%), high good and low defective kernel ratio in G_4 (85.35%), and high BA in G_{11} (99.37%) clones. As a result of this study, indicated that G_1, G_6, G_4, and G_{11} clones are promising for hazelnut production.

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Statement of Research and Publication Ethics

The author declares that this study complies with Research and Publication Ethics.

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