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***Araştırma (Research)***

# Yield Characteristics and Nut Defects of 'Karafındık' Hazelnut Clones Grown in Fatsa (Ordu)*

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**Abstract**

**Objective:** The main aim of this study to determine the yield characteristics, nut and kernel defects of 'Karafındık' hazelnut clones grown in Fatsa (Ordu) district.

**Materials and Methods:** The plant material of the study was 'Karafındık' hazelnut clones grown in region. In the study, the cluster number, nuts per cluster, plant yield, yield efficiency, and yield fluctuation were determined as yield characteristics; good kernel, defective kernel, blank nut, shriveled kernel, twin kernel, abortive kernel, black tipped kernel, moldy kernel, and rotten kernel were determined as nut defects.

**Results:** The differences between cluster number, nuts per cluster, plant yield, yield efficiency, and good kernel ratio were found to be statistically significant ($p<0.05$). In the clones examined, the nuts per cluster was determined 2.30 (KF-53)-3.72 (KF-48), the plant yield was determined 93 g plant$^{-1}$ (KF-53)-758 g plant$^{-1}$ (KF-16), the yield efficiency was determined 2.03 g cm$^{-2}$ (KF-53)-26.99 g cm$^{-2}$ (KF-11), the good kernel was determined %60.9 (KF-23, KF-25)-%97.4 (KF-42), the defective kernel was determined %2.6 (KF-42)-%37.4 (KF-25), and the blank nut was determined %0.0 (in 16 different clones)-%14.4 (KF-23).

**Conclusion:** It was determined that there were fluctuations in the yield amount of the clones from year to year, while KF-16, KF-20, KF-1, and KF-49 clones had the highest plant yield.

**Keywords:** *Corylus avellana*, defective kernel, good kernel, yield efficiency, yield fluctuation

## Fatsa (Ordu)'da Yetiştirilen 'Karafındık' Fındık Klonlarının Verim Özellikleri ve Meyve Kusurları

**Öz**

**Amaç:** Bu çalışma Fatsa (Ordu) ilçesinde yetişen 'Karafındık' fındık çeşidine ait klonların verim özellikleri ile kabuklu ve iç meyve kusurlarını belirlemek amacıyla yürütülmüştür.

**Materyal ve Yöntem:** Çalışmanın bitkisel materyalini yörede yetiştirilen 'Karafındık' fındık klonları oluşturmaktadır. Araştırmada verim özellikleri olarak çotanak sayısı, çotanaktaki meyve sayısı, bitki verimi, verim etkinliği ve verim dalgalanması; meyve kusurları olarak sağlam iç oranı, kusurlu iç oranı, boş meyve oranı, buruşuk iç oranı, ikiz iç oranı, eksik (abortif) iç oranı, siyah uçlu iç oranı, küflü iç oranı ve çürük iç oranı belirlenmiştir.

**Araştırma Bulguları:** Çalışmada, çotanak sayısı, çotanaktaki meyve sayısı, verim, verim etkinliği ve sağlam meyve oranı bakımından klonlar arasındaki farklılıklar istatistiksel olarak önemli bulunmuştur ($p<0.05$). İncelenen klonlarda, çotanaktaki meyve sayısı 2.30 (KF-53)-3.72 (KF-48), verim 93 g bitki$^{-1}$ (KF-53)-758 g bitki$^{-1}$ (KF-16), verim etkinliği 2.03 g cm$^{-2}$ (KF-53)-26.99 g cm$^{-2}$ (KF-11), sağlam meyve oranı %60.9 (KF-23, KF-25)-%97.4 (KF-42), kusurlu meyve oranı %2.6 (KF-42)-%37.4 (KF-25) ve boş meyve oranı %0.0 (16 farklı klonda)-%14.4 (KF-23) olarak tespit edilmiştir.

**Sonuç:** Çalışmada, yıldan yıla klonların verim miktarlarında dalgalanmalar meydana gelirken, en yüksek bitki verimi KF-16, KF-20, KF-1, ve KF-49 klonlarında tespit edilmiştir.

**Anahtar kelimeler:** *Corylus avellana*, kusurlu iç oranı, sağlam iç oranı, verim etkinliği, verim dalgalanması

## Introduction

Hazelnut is a species of nut that is botanically included in the genus *Corylus* of the *Fagales* order *Betulaceae* family (Botta et al., 2019). There are 9-25 species in the form of trees and shrubs in the genus Corylus (İslam, 2019). Among the nut trees, the European hazelnut (*Corylus avellana* L.) is one of the most significant species. Hazelnut is one of the leading products among nuts in terms of nutritional content. Its kernels contain 60-70% fat, 15-18% carbohydrates, and 10-16% protein (Preece and Aradhya, 2019). In addition, the fibers, unsaturated fatty acids, sterols, phytochemicals, tocopherols, polyphenols, minerals, and vitamins in their structure increase its nutritional value (Alasalvar et al., 2006; Guiné and Correia, 2020; Koyuncu et al., 1997). Due to its high nutritional value, benefits to human health, and abundant industrial use opportunities, hazelnut increases its economic importance locally and globally in terms of consumers and producers. The high industrial demand for the nuts of this species all over the world has led to an increase in production and cultivation areas (Pacchiarelli et al., 2022).

Türkiye (684,000 t), Italy (84.670 t), USA (70.310), Azerbaijan (67,630 t), Georgia (46,000 t), Chile (35.291 t), and China (24.422 t) are listed as important producing countries worldwide in 2021 (FAOSTAT, 2023). Ordu (239.935 t) is where the highest hazelnut production is carried out in Türkiye in 2022, followed by the provinces of Samsun (111.701 t), Sakarya (98.469 t), Giresun (92.305 t), Düzce (83.052 t), and Trabzon (52.461 t), respectively (TUIK, 2023). Although hazelnut orchards in Ordu are mainly established with Palaz, Tombul, and Çakıldak cultivars, different hazelnut cultivars such as Kalınkara, Incekara, and Karafındık are also found in orchards at lower rates in the region (Bostan, 1997). 'Karafındık' cultivar is seen as one of the high-quality hazelnut cultivars (Dundar and Altundag, 2004). It is a cultivar with round shaped, large nut, high oil content, productive, high adaptability, resistant to diseases, pests and late spring frosts (Köksal, 2018). Karafındık, frequently used in orchards, is generally preferred as a pollinator cultivar in the region. Also called 'Karayağlı' in some regions, it is a highly productive cultivar, the husk of which is less long and slit, the kernels are fiberless, and the nuts per cluster is defined as 3 (Balik et al., 2016; Köksal, 2018).

High yield and low rate of nut defects are among the common targets of hazelnut breeding (Botta et al., 2019). The rapid increase in the world population has led to the need to increase agricultural production productivity to meet people's nutritional needs (Tian et al., 2021). Increasing productivity in hazelnut production is important both to respond to this demand and increase the producers' income. On the other hand, improving the quality characteristics of fruits is important as it affects consumer demands and the market value of the products (Rahman et al., 2021). Nut and kernel defects negatively affect the commercial value of hazelnut (Silvestri et al., 2021). It is known that nut and kernel defects in hazelnut cause physical, chemical, or microbiological changes, which occur with the effect of various factors in nuts' growth, development, and maturation processes (Bostan, 2019).

In this study, it was aimed to determine the yield characteristics and nut defects of the 'Karafındık' hazelnut population grown in the Fatsa (Ordu) region.

## Material and Methods

### Plant Materials

This study was carried out in Fatsa district of Ordu province in 2015-2018. The plant material of the study consisted of 53 clones from the 'Karafındık' hazelnut population of the region, which were determined by considering the breeding criteria (high yield, high percent kernel, large nut size, and low percentage of nuts with defects).

### Methods

The clones included in the study were determined based on field surveys conducted in the first year, discussions with producers, and observations based on breeding criteria. The clones that were identified were assigned clone numbers starting with KF-1. All cultural practices except irrigation in the orchards where the study was carried out were done by the producers. In the clones, the yield characteristics for four years and the characteristics of nut defects for three years (2015, 2016, 2017) were examined.

**Yield Characteristics**

As yield characteristics, cluster number, nuts per cluster, plant yield, yield efficiency, and yield fluctuation were determined in the study. The cluster number was determined by counting all the clusters on the plant. The plant yield was calculated by multiplying the total number of clusters, the number of nuts in clusters, and the average nut weight obtained from the clones. In the yield calculation, good kernels were evaluated. Yield efficiency was determined by dividing the yield per plant in each clone by the trunk cross-sectional area. The trunk cross-sectional area was calculated according to the $\pi r^2$ formula after measuring the trunk diameter in two directions from 20 cm above the soil level and averaging it (Çalışkan et al., 2019). Yield fluctuation, the annual plant yield values obtained from the clones were calculated using the following formula as ±% change according to the average plant yield for four years. Yield fluctuation (%) = [(Average yield / Annual yield) × 100]

**Good kernel, blank nut, and defective kernel (%)**

Good kernel, blank nut, and defective kernel ratios were determined after breaking 100 nuts of each clone. Good kernel ratio (%) was determined by dividing the nuts that have filled the shell inside and have no defects by the total number of nuts. Blank nut (%) was determined by the ratio of the nuts that did not form any seeds in the shell to the total number of nuts. Defective kernel (%) was calculated by dividing the remaining kernels excluding good kernel and blank nuts, by the total number of nuts. As kernel defects, shriveled kernel, double kernel, abortive kernel, black tipped kernel, moldy kernel, and rotten kernel were evaluated (Güler and Balta, 2020).

**Statistical Analysis**

Statistical analyzes were performed using the JMP 14 statistical package program. Differences between clones in terms of traits examined were determined at the 5% significance level using the LSD multiple comparison method. Principal component analysis was performed according to the examined clones' yield characteristics and nut defects.

**Results and Discussion**

There are many factors, such as genetic structure, nutritional status of the plant, ecological conditions, technical and cultural practices, etc., on productivity, which is an important character in hazelnut cultivation and breeding. In the study, the differences between the cluster number, the nuts per cluster, and yield efficiency of the 'Karafındık' clones was found to be statistically significant ($p<0.05$). The cluster number was determined 22.8 (KF-10)-134.0 (KF-16, KF-51) (Table 1). The clones with the highest cluster number were KF-16 and KF-51 (134 pcs plant$^{-1}$), while KF-20, KF-11, KF-46, KF-17, KF-52, KF-6, and KF-41 clones stood out with cluster exceeding 100. The nuts per cluster was determined 2.30 (KF-53)-3.72 (KF-48) (Table 1). It was reported the nuts per cluster as 3.0 in the standard Karafındık cultivar (Köksal, 2018). In previous studies, the nuts per cluster had been reported; in Ordu, 3.50-6.50 for the Kalınkara (İslam, 2000); in Samsun, 3.71 for the Kalınkara (Beyhan and Demir, 2001); in Giresun, 2.20-5.42 for standard hazelnut cultivars and genotypes (Yılmaz, 2009); in Mudurnu (Bolu), 3.60-4.47 for the Karayağlı (Karafındık) clones (Güler and Balta, 2020). Accordingly, it can be stated that the results obtained from this study generally exhibit similarities with the existing literature. In 23 of the examined clones, the nuts per cluster were found to be higher than the value reported by Köksal (2018) for the standard Karafındık cultivar. Among these clones, KF-48 (3.72), KF-21 (3.49), KF-31 (3.42), KF-52 (3.39), KF-14 (3.34), KF-30 (3.32), KF-37 (3.31), and KF-15 (3.30) stood out with the highest values. The yield efficiency was determined 2.03 g cm$^{-2}$ (KF-53)-26.99 g cm$^{-2}$ (KF-11) in clones examined (Table 1). In the study, following KF-11 clone, the highest yield efficiency was determined in KF-48 (23.66), KF-31 (17.40), KF-14 (17.15), KF-3 (14.03), KF-13 (13.39), and KF-47 (11.45) clones. In related studes, the yield efficiency was 6.7-89.6 g cm$^{-2}$ for Tonda di Giffoni clones in Italy (Petriccione et al., 2008); 21.0-34.0 g cm$^{-2}$ for Tombul cultivar, 24.0-74.0 g cm$^{-2}$ for Palaz cultivar in Çarsamba (Samsun) (Çalışkan, 2018); 55.86 g cm$^{-2}$ for PollyO cultivar, 77.01 g cm$^{-2}$ for Yamhill cultivar, 62.01 g cm$^{-2}$ for Jefferson cultivar (Mehlenbacher et al., 2019). While it is possible to establish a relationship between the yield efficiency values determined in the examined clones and those reported by Petriccione et al. (2008) and Çalışkan (2018), it can be stated that the yield efficiency is relatively lower compared to the foreign cultivars mentioned in other studies. Throughout the course of the study, varying levels of yield fluctuations occurred among the examined clones over the years. The yield fluctuation was determined %-22 (KF-44)-%+224 (KF-25) in 2015, %-92 (KF-37)-%+39 (KF-30) in 2016, %-68 (KF-25)-%+100 (KF-34) in 2017, and %-89 (KF-20)-%+47 (KF-51) in 2018 (Table 2).

Table 1. The cluster number (pcs plant$^{-1}$), the number of nuts per cluster (pcs) and, yield efficiency (g cm$^{-2}$) of the investigated Karafındık clones

| Clones | Cluster number | Nuts per cluster | Yield efficiency |
|---|---|---|---|
| **KF-1** | 68.3 | 2.35 | 3.64 |
| **KF-2** | 71.8 | 3.00 | 6.55 |
| **KF-3** | 61.5 | 3.15 | 14.03 |
| **KF-4** | 51.8 | 3.28 | 8.91 |
| **KF-5** | 66.0 | 2.92 | 3.22 |
| **KF-6** | 99.5 | 3.10 | 8.11 |
| **KF-7** | 76.5 | 3.07 | 6.22 |
| **KF-8** | 76.8 | 2.75 | 5.49 |
| **KF-9** | 39.8 | 2.73 | 9.67 |
| **KF-10** | 22.8 | 2.84 | 5.74 |
| **KF-11** | 109.8 | 3.19 | 26.99 |
| **KF-12** | 50.3 | 2.82 | 8.83 |
| **KF-13** | 69.0 | 3.01 | 13.39 |
| **KF-14** | 88.0 | 3.34 | 17.15 |
| **KF-15** | 62.3 | 3.30 | 5.52 |
| **KF-16** | 134.0 | 2.82 | 6.46 |
| **KF-17** | 105.0 | 2.79 | 7.53 |
| **KF-18** | 56.5 | 3.13 | 6.35 |
| **KF-19** | 96.3 | 2.97 | 7.10 |
| **KF-20** | 119.0 | 2.94 | 9.18 |
| **KF-21** | 43.8 | 3.49 | 8.63 |
| **KF-22** | 47.5 | 2.86 | 9.20 |
| **KF-23** | 53.0 | 2.85 | 8.57 |
| **KF-24** | 29.0 | 2.70 | 4.74 |
| **KF-25** | 30.0 | 2.79 | 9.90 |
| **KF-26** | 37.0 | 2.43 | 7.27 |
| **KF-27** | 24.8 | 2.92 | 4.87 |
| **KF-28** | 58.5 | 2.97 | 9.56 |
| **KF-29** | 63.0 | 2.87 | 8.37 |
| **KF-30** | 43.8 | 3.32 | 5.27 |
| **KF-31** | 64.5 | 3.42 | 17.40 |
| **KF-32** | 33.5 | 3.08 | 3.29 |
| **KF-33** | 35.3 | 3.01 | 4.32 |
| **KF-34** | 45.3 | 2.97 | 6.10 |
| **KF-35** | 39.3 | 3.10 | 5.67 |
| **KF-36** | 68.3 | 3.00 | 7.85 |
| **KF-37** | 71.8 | 3.31 | 7.41 |
| **KF-38** | 61.5 | 2.51 | 3.38 |
| **KF-39** | 51.8 | 2.90 | 7.35 |
| **KF-40** | 66.0 | 2.86 | 7.10 |
| **KF-41** | 99.5 | 3.15 | 3.33 |
| **KF-42** | 76.5 | 2.80 | 4.97 |
| **KF-43** | 76.8 | 3.24 | 2.80 |
| **KF-44** | 39.8 | 3.10 | 4.17 |
| **KF-45** | 22.8 | 2.64 | 3.45 |
| **KF-46** | 109.8 | 2.50 | 6.46 |
| **KF-47** | 50.3 | 3.25 | 11.45 |
| **KF-48** | 69.0 | 3.72 | 23.66 |
| **KF-49** | 88.0 | 3.25 | 9.70 |
| **KF-50** | 62.3 | 2.91 | 3.53 |
| **KF-51** | 134.0 | 2.97 | 4.80 |
| **KF-52** | 105.0 | 3.39 | 4.07 |
| **KF-53** | 56.5 | 2.30 | 2.03 |
| **Min** | 22.8 | 2.30 | 2.03 |
| **Max** | 134.0 | 3.72 | 26.99 |
| **Mean** | 65.7 | 2.98 | 7.75 |
| **SD** | 27.7 | 0.29 | 4.82 |
| **CV (%)** | 0.42 | 0.10 | 0.62 |
| **Significance** | * | ** | *** |
| **LSD (0.05)** | 55.66 | 0.57 | 8.15 |

Table 2. Yield (g plant$^{-1}$) and yield fluctuation (% ±) of the investigated Karafındık clones

| Clones | ±% change of annual yields according to 4-year average yield value | | | | | | | | Avg. Plant Yield (g bitki$^{-1}$) |
|---|---|---|---|---|---|---|---|---|---|
| | 2015 | % ± | 2016 | % ± | 2017 | % ± | 2018 | % ± | |
| **KF-1** | 780 | +132 | 311 | -7 | 196 | -41 | 55 | -83 | **336** |
| **KF-2** | 793 | +94 | 360 | -12 | 330 | -19 | 153 | -63 | **409** |
| **KF-3** | 379 | +12 | 260 | -23 | 354 | +4 | 364 | +7 | **339** |
| **KF-4** | 305 | +10 | 191 | -31 | 238 | -14 | 373 | +35 | **277** |
| **KF-5** | 636 | +112 | 157 | -48 | 276 | -8 | 132 | -56 | **300** |
| **KF-6** | 740 | +47 | 364 | -28 | 436 | -14 | 477 | -5 | **504** |
| **KF-7** | 677 | +64 | 149 | -64 | 464 | +12 | 360 | -13 | **413** |
| **KF-8** | 578 | +58 | 236 | -36 | 367 | 0 | 283 | -23 | **366** |
| **KF-9** | 386 | +99 | 77 | -60 | 173 | -10 | 138 | -29 | **193** |
| **KF-10** | 141 | +13 | 155 | +24 | 44 | -65 | 158 | +27 | **124** |
| **KF-11** | 583 | -12 | 800 | +21 | 584 | -12 | 685 | +3 | **663** |
| **KF-12** | 536 | +107 | 44 | -83 | 353 | +37 | 100 | -61 | **258** |
| **KF-13** | 590 | +39 | 258 | -39 | 587 | +39 | 259 | -39 | **424** |
| **KF-14** | 604 | +16 | 503 | -3 | 372 | -29 | 605 | +16 | **521** |
| **KF-15** | 573 | +46 | 195 | -50 | 497 | +27 | 302 | -23 | **392** |
| **KF-16** | 1522 | +101 | 396 | -48 | 869 | +15 | 244 | -68 | **758** |
| **KF-17** | 914 | +93 | 68 | -86 | 831 | +76 | 78 | -84 | **473** |
| **KF-18** | 461 | +60 | 164 | -43 | 421 | +46 | 107 | -63 | **288** |
| **KF-19** | 728 | +49 | 181 | -63 | 825 | +69 | 221 | -55 | **489** |
| **KF-20** | 1179 | +68 | 680 | -3 | 871 | +24 | 79 | -89 | **702** |
| **KF-21** | 443 | +72 | 159 | -39 | 252 | -2 | 179 | -31 | **258** |
| **KF-22** | 363 | +50 | 154 | -36 | 272 | +12 | 179 | -26 | **242** |
| **KF-23** | 579 | +128 | 61 | -76 | 200 | -21 | 176 | -31 | **254** |
| **KF-24** | 456 | +187 | 36 | -77 | 98 | -38 | 45 | -72 | **159** |
| **KF-25** | 763 | +224 | 46 | -80 | 74 | -68 | 60 | -75 | **236** |
| **KF-26** | 637 | +210 | 36 | -82 | 99 | -52 | 50 | -76 | **205** |
| **KF-27** | 160 | +55 | 40 | -61 | 115 | +12 | 98 | -5 | **103** |
| **KF-28** | 427 | +42 | 80 | -73 | 365 | +21 | 332 | +10 | **301** |
| **KF-29** | 400 | +30 | 123 | -60 | 386 | +25 | 321 | +4 | **308** |
| **KF-30** | 253 | +7 | 329 | +39 | 277 | +17 | 86 | -64 | **236** |
| **KF-31** | 560 | +57 | 67 | -81 | 669 | +87 | 135 | -62 | **358** |
| **KF-32** | 255 | +67 | 69 | -55 | 178 | +17 | 109 | -29 | **153** |
| **KF-33** | 259 | +50 | 80 | -54 | 223 | +29 | 128 | -26 | **173** |
| **KF-34** | 346 | +54 | 45 | -80 | 450 | +100 | 60 | -73 | **225** |
| **KF-35** | 372 | +63 | 34 | -85 | 427 | +88 | 78 | -66 | **228** |
| **KF-36** | 372 | +71 | 48 | -78 | 384 | +76 | 67 | -69 | **218** |
| **KF-37** | 682 | +97 | 28 | -92 | 604 | +74 | 71 | -79 | **347** |
| **KF-38** | 193 | +57 | 41 | -67 | 206 | +67 | 53 | -57 | **123** |
| **KF-39** | 323 | +27 | 179 | -30 | 339 | +33 | 177 | -30 | **254** |
| **KF-40** | 296 | +17 | 154 | -39 | 380 | +49 | 186 | -27 | **254** |
| **KF-41** | 336 | +46 | 155 | -33 | 259 | +13 | 170 | -26 | **230** |
| **KF-42** | 333 | +5 | 170 | -46 | 560 | +77 | 201 | -36 | **316** |
| **KF-43** | 168 | -17 | 197 | -2 | 226 | +12 | 215 | +7 | **202** |
| **KF-44** | 220 | -22 | 176 | -38 | 553 | +96 | 182 | -36 | **283** |
| **KF-45** | 207 | +1 | 134 | -34 | 289 | +41 | 187 | -8 | **204** |
| **KF-46** | 435 | +47 | 136 | -54 | 268 | -9 | 342 | +16 | **295** |
| **KF-47** | 699 | +49 | 134 | -71 | 590 | +26 | 455 | -3 | **469** |
| **KF-48** | 821 | +90 | 209 | -52 | 158 | -64 | 543 | +26 | **433** |
| **KF-49** | 973 | +52 | 394 | -38 | 642 | 0 | 551 | -14 | **640** |
| **KF-50** | 812 | +132 | 166 | -52 | 307 | -12 | 115 | -67 | **350** |
| **KF-51** | 408 | +38 | 147 | -50 | 195 | -34 | 434 | +47 | **296** |
| **KF-52** | 725 | +46 | 165 | -67 | 782 | +58 | 308 | -38 | **495** |
| **KF-53** | 159 | +72 | 27 | -71 | 143 | +54 | 42 | -55 | **93** |
| **Min** | | | | | | | | | **93** |
| **Max** | | | | | | | | | **758** |
| **Mean** | | | | | | | | | **324** |
| **SD** | | | | | | | | | **151** |
| **CV (%)** | | | | | | | | | **0.46** |
| **Significance** | | | | | | | | | ** |
| **LSD (0.05)** | | | | | | | | | **313.30** |

In the study, the differences between the plant yield of the 'Karafındık' clones were found to be statistically significant ($p<0.05$). According to the average of the four-year data, the plant yield varied between 93 g plant$^{-1}$ (KF-53) and 758 g plant$^{-1}$ (KF-16). In related studies, the plant yield has been reported; in Ordu 335.80-527.41 g plant$^{-1}$ for Tombul cultivar (Çalış, 2010); in Mudurnu (Bolu) 414.0-529.1 g plant$^{-1}$ for Karayağlı (Karafındık) clones (Güler and Balta, 2020); in Perşembe (Ordu) 419.69-453.67 g plant$^{-1}$ for Tombul clones (İslam and Çalış, 2018). Generally, the yield values obtained from the examined clones show similarities with the values reported in the literature. However, in this study, in addition to KF-16 (758 g plant-1), which had the highest plant yield, KF-20 (702 g plant-1), KF-11 (663 g plant-1), KF-49 (640 g plant-1), KF-14 (521 g plant-1), and KF-6 (504 g plant-1) clones also stood out with their high yields.

In the study, the differences between the good kernel ratio of the 'Karafındık' clones were found to be statistically significant ($p<0.05$). Determined the clones examined, the good kernel was %60.9 (KF-23, KF-25)-%97.4 (KF-42), the defective kernel was %2.6 (KF-42)-%37.4 (KF-25), the blank nut was %0.0 (in 16 different clones)-%14.4 (KF-23), the shriveled kernel %0.0 (in 10 different clones)-%8.3 (KF-37), twin kernel was %0.0 (KF-47)-%19.0 (KF-3), abortive kernel was %0.0 (KF-6, KF-9, KF-18, KF-36, KF-42, KF-45, KF-48)-%10.0 (KF-19), black tipped kernel was %0.0 (in 39 different clones)-%4.4 (KF-49), moldy kernel was %0.0 (in 31 different clones)-%4.4 (KF-16), and rotten kernel was %0.0 (in 26 different clones)-%6.9 (KF-38) (Table 3, Table 4).

In related studies in Türkiye, it has been reported; good kernel %65.09-97.62, twin kernel %1.11-24.53 in Kalınkara cultivar (İslam, 2000); good kernel %95 in Kalınkara cultivar (Beyhan and Demir, 2001); shriveled kernel %3.53, blank nut %4.25, good kernel %80.00, and twin kernel %10.23 in Kalınkara cultivar (Bostan and Günay, 2009); good kernel %74 and %63, defective kernel %22 and %28, blank nut %3.33 and %8.33 in Karayağlı (Karafındık) clones (Güler and Balta, 2020).

Regarding fruit defects in foreign cultivars, it has been reported; good kernel %80.7, blank nut %7.5, moldy kernel %4.2, shriveled kernel %4.3, twin kernel %0.1 and black tipped kernel %1.2 in Dorris cultivar (Mehlenbacher et al., 2013); good kernel %86.7, blank nut %7.6, shriveled kernel %2.7, moldy kernel %1.1, black tipped kernel %0.3, and twin kernel %0.1 in Wepster cultivar (Mehlenbacher et al., 2014); good kernel %93, blank nut %2.5, moldy kernel %3.4, shriveled kernel %0.3, twin kernel %0.1, black tipped kernel %0.4 in PollyO cultivar (Mehlenbacher et al., 2019).

Defects in fruits cause serious problems, especially with quality parameters and yield amount, and generate economic losses. In terms of nut and kernel defects examined in the study, the values obtained from the Karafındık hazelnut clones were generally compatible with the studies carried out in Türkiye and foreign cultivars. On the other hand, although nut and kernel defects in hazelnut occur genetically, differences in these characteristics can be seen from year to year (Mehlenbacher et al., 1993). In addition, it is stated that factors such as the nutritional status of the plant (Özkutlu et al., 2016), cultural and technical treatments (Balta et al., 2021), plant age, and product load (McCluskey et al., 2005) may affect the occurrence of these defects.

For principal component analysis, 13 features of the clones examined were used. The eigenvalues of the first 5 components were found to be above 1 and explained 75.35% of the data obtained. PC 1 was associated with the defective kernel, good kernel, twin kernel, and abortive kernel and explained 26.38% of the total variation. The defective kernel (0.92) was the most effective parameter on PC 1. While PC 2 explained 17.8% of the total variation, it was associated with yield, cluster number, abortive kernel, and moldy kernel. Yield (0.80) was the most effective parameter on PC 2. Moreover, PC 3 was related to shriveled kernel, moldy kernel, blank nut, black tipped kernel, and good kernel features; PC 4 was related to nuts per cluster, yield efficiency, and plant yield features; and PC 5 was related to rotten kernel and black tipped kernel features (Table 5; Figure 1).

In the dendrogram created using yield characteristics and nut defects, Karafındık clones have been divided into two main clusters. The majority of the clones are grouped within Cluster B, and the clones within Cluster B are further subdivided into two subgroups. Within these subgroups, B1 contains 24 clones, while B2 contains 14 clones. Cluster A is composed of the following clones: KF-1, KF-40, KF-12, KF-22, KF-19, KF-23, KF-24, KF-53, KF-26, KF-34, KF-39, KF-38, KF-3, KF-25, and KF-44 (Figure 2).

Table 3. The ratios of good kernel, defective kernel, blank nut, shriveled kernel, and twin kernel of the investigated Karafındık clones (%)

| Clones | Good Kernel (%) | Defective Kernel (%) | Blank Nut (%) | Shriveled Kernel (%) | Twin Kernel (%) |
|---|---|---|---|---|---|
| **KF-1** | 82.8 | 12.1 | 5.1 | 0.3 | 7.6 |
| **KF-2** | 79.4 | 15.6 | 5.0 | 1.8 | 9.7 |
| **KF-3** | 66.3 | 32.1 | 1.7 | 4.4 | 19.0 |
| **KF-4** | 87.8 | 12.2 | 0.0 | 5.0 | 1.1 |
| **KF-5** | 78.3 | 20.0 | 1.7 | 6.0 | 8.3 |
| **KF-6** | 86.7 | 13.3 | 0.0 | 4.4 | 8.5 |
| **KF-7** | 86.1 | 10.2 | 3.7 | 3.0 | 2.7 |
| **KF-8** | 74.8 | 23.0 | 2.2 | 2.2 | 18.9 |
| **KF-9** | 75.6 | 18.9 | 5.6 | 3.3 | 13.3 |
| **KF-10** | 84.9 | 13.8 | 1.3 | 5.1 | 6.6 |
| **KF-11** | 82.6 | 17.4 | 0.0 | 0.0 | 8.5 |
| **KF-12** | 82.2 | 14.4 | 3.3 | 1.1 | 3.3 |
| **KF-13** | 87.8 | 12.2 | 0.0 | 2.2 | 5.6 |
| **KF-14** | 81.1 | 15.6 | 3.3 | 3.9 | 10.0 |
| **KF-15** | 77.8 | 22.2 | 0.0 | 1.7 | 10.1 |
| **KF-16** | 78.5 | 19.3 | 2.2 | 5.9 | 0.4 |
| **KF-17** | 81.1 | 18.9 | 0.0 | 0.0 | 12.8 |
| **KF-18** | 80.4 | 16.3 | 3.3 | 0.4 | 15.2 |
| **KF-19** | 67.8 | 22.2 | 10.0 | 2.2 | 10.0 |
| **KF-20** | 81.7 | 18.3 | 0.0 | 2.2 | 7.2 |
| **KF-21** | 76.1 | 21.7 | 2.2 | 5.9 | 11.2 |
| **KF-22** | 72.3 | 22.3 | 5.4 | 4.3 | 9.3 |
| **KF-23** | 60.9 | 24.6 | 14.4 | 4.6 | 11.0 |
| **KF-24** | 69.6 | 23.1 | 7.3 | 6.3 | 14.4 |
| **KF-25** | 60.9 | 37.4 | 1.7 | 4.9 | 14.0 |
| **KF-26** | 71.0 | 17.3 | 11.7 | 8.0 | 5.3 |
| **KF-27** | 85.1 | 14.2 | 0.7 | 3.0 | 7.3 |
| **KF-28** | 81.5 | 18.5 | 0.0 | 0.0 | 14.4 |
| **KF-29** | 76.7 | 23.3 | 0.0 | 7.8 | 10.0 |
| **KF-30** | 79.3 | 14.7 | 6.0 | 1.7 | 12.2 |
| **KF-31** | 90.0 | 7.7 | 2.3 | 2.7 | 3.3 |
| **KF-32** | 83.6 | 11.9 | 4.4 | 0.0 | 6.7 |
| **KF-33** | 73.3 | 26.7 | 0.0 | 4.4 | 18.9 |
| **KF-34** | 70.4 | 22.1 | 7.4 | 2.0 | 8.3 |
| **KF-35** | 82.8 | 14.9 | 2.3 | 4.7 | 7.7 |
| **KF-36** | 84.1 | 14.3 | 1.7 | 0.7 | 10.1 |
| **KF-37** | 85.0 | 12.7 | 2.3 | 8.3 | 1.0 |
| **KF-38** | 74.7 | 20.9 | 4.4 | 6.2 | 3.2 |
| **KF-39** | 69.0 | 25.0 | 6.0 | 4.0 | 8.0 |
| **KF-40** | 77.7 | 11.7 | 10.7 | 2.7 | 4.7 |
| **KF-41** | 85.9 | 9.1 | 5.0 | 4.3 | 1.1 |
| **KF-42** | 97.4 | 2.6 | 0.0 | 0.3 | 2.2 |
| **KF-43** | 95.4 | 4.2 | 0.3 | 0.0 | 0.7 |
| **KF-44** | 66.7 | 31.7 | 1.7 | 5.5 | 15.5 |
| **KF-45** | 89.6 | 10.4 | 0.0 | 1.1 | 7.4 |
| **KF-46** | 91.1 | 8.9 | 0.0 | 0.0 | 4.4 |
| **KF-47** | 92.2 | 6.7 | 1.1 | 0.0 | 0.0 |
| **KF-48** | 80.3 | 18.6 | 1.1 | 2.6 | 4.7 |
| **KF-49** | 77.8 | 22.2 | 0.0 | 2.2 | 8.9 |
| **KF-50** | 86.7 | 13.3 | 0.0 | 0.0 | 7.8 |
| **KF-51** | 91.1 | 8.9 | 0.0 | 0.0 | 4.4 |
| **KF-52** | 84.2 | 12.3 | 3.4 | 0.0 | 9.3 |
| **KF-53** | 68.9 | 23.8 | 7.3 | 5.0 | 16.1 |
| **Min** | 60.9 | 2.6 | 0.0 | 0.0 | 0.0 |
| **Max** | 97.4 | 37.4 | 14.4 | 8.3 | 19.0 |
| **Mean** | 79.9 | 17.1 | 3.0 | 3.0 | 8.4 |
| **SD** | 8.3 | 7.0 | 3.4 | 2.4 | 5.0 |
| **CV (%)** | 0.10 | 041 | 1.13 | 0.80 | 0.59 |
| **Significance** | * | ns | ns | ns | ns |
| **LSD (0.05)** | 18.53 | 16.88 | 8.46 | 6.87 | 12.09 |

Table 4. The ratios of abortive kernel, black-tip kernel, moldy kernel, and rotten kernel of the investigated Karafındık clones (%)

| Clones | Abortive Kernel (%) | Black tipped Kernel (%) | Moldy Kernel (%) | Rotten Kernel (%) |
|---|---|---|---|---|
| **KF-1** | 4.2 | 0.0 | 0.0 | 0.0 |
| **KF-2** | 2.1 | 0.0 | 1.3 | 0.8 |
| **KF-3** | 6.4 | 0.0 | 1.1 | 1.1 |
| **KF-4** | 3.9 | 0.0 | 0.0 | 2.2 |
| **KF-5** | 3.9 | 0.0 | 1.1 | 0.7 |
| **KF-6** | 0.0 | 0.0 | 0.0 | 0.4 |
| **KF-7** | 2.7 | 0.7 | 1.0 | 0.0 |
| **KF-8** | 1.9 | 0.0 | 0.0 | 0.0 |
| **KF-9** | 0.0 | 0.0 | 0.0 | 2.2 |
| **KF-10** | 1.0 | 0.0 | 0.0 | 1.1 |
| **KF-11** | 8.9 | 0.0 | 0.0 | 0.0 |
| **KF-12** | 6.7 | 1.7 | 1.7 | 0.0 |
| **KF-13** | 4.4 | 0.0 | 0.0 | 0.0 |
| **KF-14** | 0.6 | 0.6 | 0.0 | 0.6 |
| **KF-15** | 2.2 | 0.0 | 2.2 | 6.0 |
| **KF-16** | 6.7 | 0.4 | 4.4 | 1.5 |
| **KF-17** | 4.4 | 1.7 | 0.0 | 0.0 |
| **KF-18** | 0.0 | 0.0 | 0.0 | 0.7 |
| **KF-19** | 10.0 | 0.0 | 0.0 | 0.0 |
| **KF-20** | 1.7 | 1.7 | 0.6 | 5.0 |
| **KF-21** | 1.7 | 0.0 | 0.3 | 2.6 |
| **KF-22** | 6.6 | 0.4 | 1.7 | 0.0 |
| **KF-23** | 7.2 | 0.0 | 1.8 | 0.0 |
| **KF-24** | 2.0 | 0.0 | 0.0 | 0.4 |
| **KF-25** | 5.9 | 0.0 | 0.3 | 0.0 |
| **KF-26** | 3.3 | 0.3 | 0.3 | 0.0 |
| **KF-27** | 3.9 | 0.0 | 0.0 | 0.0 |
| **KF-28** | 3.0 | 0.0 | 1.1 | 0.0 |
| **KF-29** | 5.6 | 0.0 | 0.0 | 0.0 |
| **KF-30** | 0.8 | 0.0 | 0.0 | 0.0 |
| **KF-31** | 1.7 | 0.0 | 0.0 | 0.0 |
| **KF-32** | 3.1 | 0.0 | 0.0 | 2.2 |
| **KF-33** | 3.3 | 0.0 | 0.0 | 0.0 |
| **KF-34** | 2.7 | 2.9 | 0.7 | 5.6 |
| **KF-35** | 0.3 | 0.0 | 0.0 | 2.2 |
| **KF-36** | 0.0 | 0.0 | 0.0 | 3.5 |
| **KF-37** | 2.3 | 0.0 | 1.0 | 0.0 |
| **KF-38** | 3.6 | 0.0 | 1.0 | 6.9 |
| **KF-39** | 5.3 | 1.0 | 0.0 | 6.7 |
| **KF-40** | 3.3 | 0.0 | 0.7 | 0.3 |
| **KF-41** | 0.7 | 0.0 | 1.3 | 1.7 |
| **KF-42** | 0.0 | 0.0 | 0.0 | 0.0 |
| **KF-43** | 3.6 | 0.0 | 0.0 | 0.0 |
| **KF-44** | 7.1 | 1.4 | 0.3 | 1.1 |
| **KF-45** | 0.0 | 1.9 | 0.0 | 0.0 |
| **KF-46** | 4.4 | 0.0 | 0.0 | 0.0 |
| **KF-47** | 1.1 | 0.0 | 0.0 | 5.6 |
| **KF-48** | 0.0 | 0.0 | 0.8 | 4.9 |
| **KF-49** | 5.6 | 4.4 | 0.0 | 1.1 |
| **KF-50** | 4.4 | 1.1 | 0.0 | 0.0 |
| **KF-51** | 3.3 | 0.0 | 0.0 | 1.1 |
| **KF-52** | 2.0 | 0.0 | 1.0 | 0.0 |
| **KF-53** | 2.7 | 0.0 | 0.0 | 0.0 |
| **Min** | 0.0 | 0.0 | 0.0 | 0.0 |
| **Max** | 10.0 | 4.4 | 4.4 | 6.9 |
| **Mean** | 3.3 | 0.4 | 0.5 | 1.3 |
| **SD** | 2.5 | 0.9 | 0.8 | 2.0 |
| **CV (%)** | 0.75 | 2.24 | 1.67 | 1.53 |
| **Significance** | ns | ns | ns | ns |
| **LSD (0.05)** | 6.49 | 2.32 | 2.56 | 5.59 |

Table 5. Principal components analysis of yield characteristics and nut defects of Karafındık hazelnut clones

| Variable | Components | | | | |
|---|---|---|---|---|---|
| | PC 1 | PC 2 | PC 3 | PC 4 | PC 5 |
| **Defective Kernel** | **0.922*** | 0.022 | 0.273 | 0,040 | 0,147 |
| **Good Kernel** | **-0.853*** | 0.009 | **-0.469*** | 0,118 | -0,092 |
| **Twin Kernel** | **0.834*** | -0.230 | -0.173 | 0,005 | -0,184 |
| **Yield** | -0.041 | **0.801*** | -0.177 | **0,415*** | 0,108 |
| **Cluster Number** | -0.293 | **0.781*** | -0.139 | 0,139 | -0,076 |
| **Abortive Kernel** | **0.462*** | **0.594*** | 0.182 | -0,167 | -0,183 |
| **Shriveled Kernel** | 0.264 | -0.178 | **0.701*** | 0,026 | 0,025 |
| **Moldy Kernel** | -0.086 | **0.515*** | **0.615*** | -0,022 | 0,210 |
| **Blank Nut** | 0.191 | -0.070 | **0.583*** | -0,367 | -0,077 |
| **Nuts Per Cluster** | -0.143 | 0.001 | -0.075 | **0,812*** | 0,170 |
| **Yield Efficiency** | 0.138 | 0.239 | -0.036 | **0,788*** | -0,080 |
| **Rotten Kernel** | -0.082 | -0.141 | 0.173 | 0,204 | **0,834*** |
| **Black Tipped Kernel** | 0.257 | 0.326 | **-0.416*** | -0,243 | **0,613*** |
| **Eigenvalue** | 3.43 | 2.31 | 1.50 | 1.38 | 1.16 |
| **Variance (%)** | 26.38 | 17.80 | 11.57 | 10.65 | 8.93 |
| **Cumulative Variance (%)** | 26.38 | 44.19 | 55.76 | 66.41 | 75.35 |

* Factor loading ≥ |0.40|

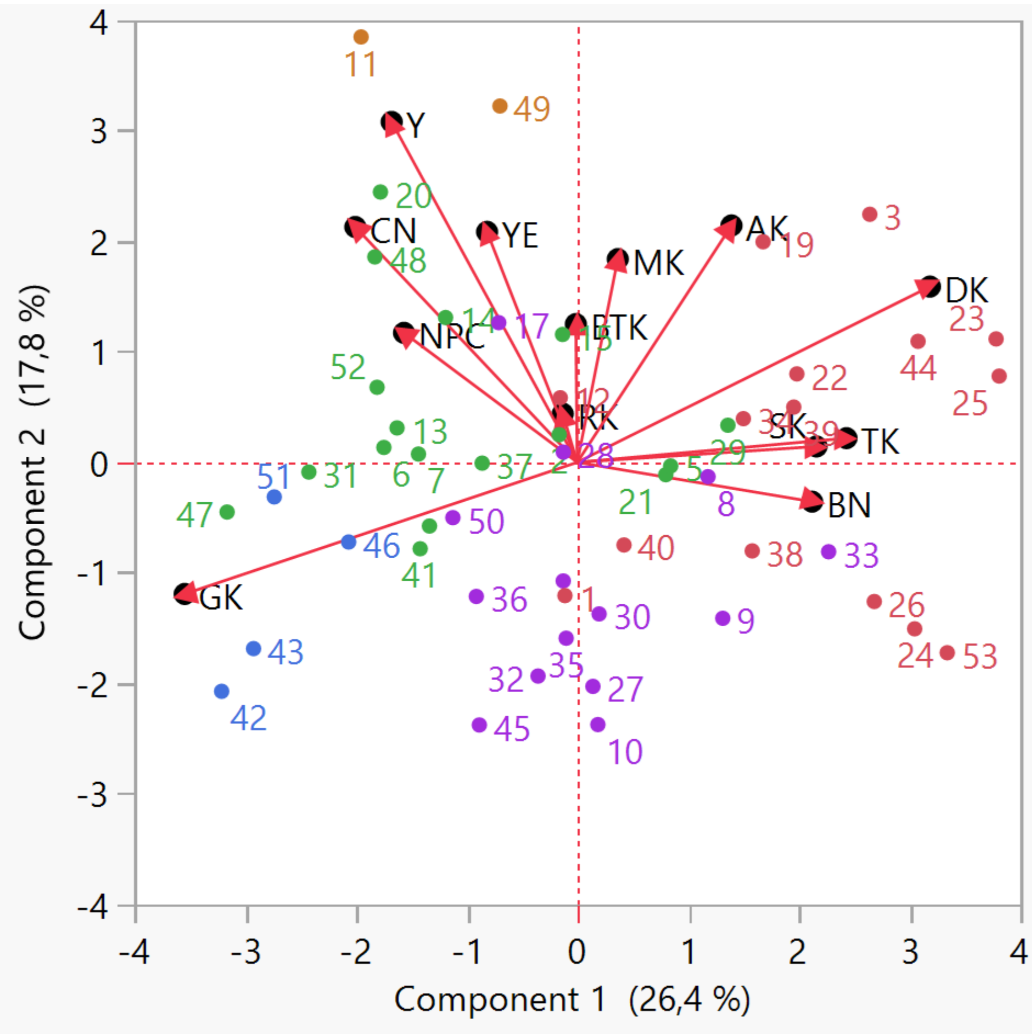


Figure 1. Component plot of the principal components (PC1 and PC2) in the investigated Karafındık clones based on yield characteristics and nut defects.

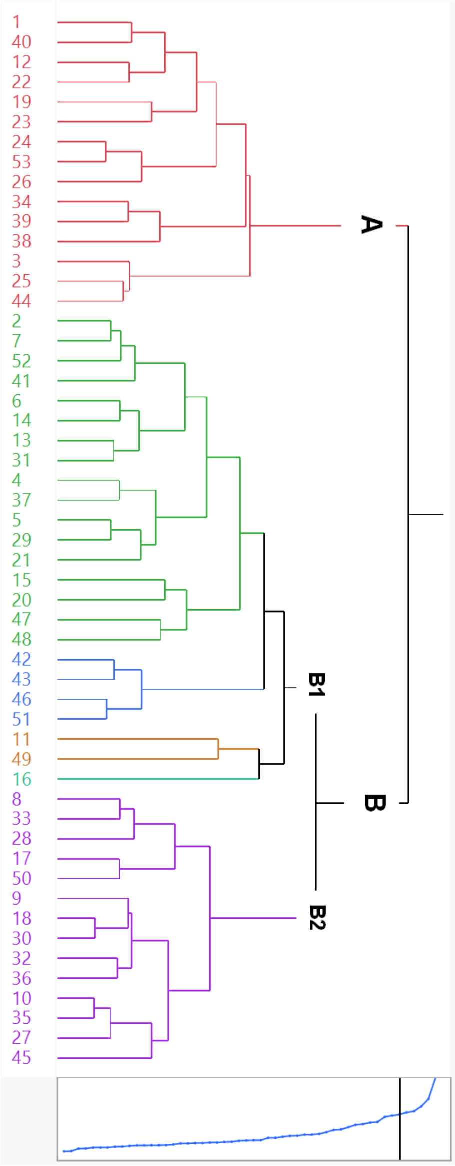


Figure 2. Dendrogram grouping of Karafındık clones based on yield characteristics and nut defects.

## Conclusion

In this study, which was carried out in Fatsa district of Ordu, the yield characteristics and nut defects of Karafındık clones in the hazelnut population of region were determined. In the examinations made in clones for 4 years, the yield amounts fluctuated from year to year. The highest yield was determined as 758 g plant$^{-1}$ in KF-16 clone. In addition, KF-20 (702 g plant$^{-1}$), KF-11 (663 g plant$^{-1}$), and KF-49 (640 g plant$^{-1}$) clones also attracted attention with their yields above 600 g. On the other hand, there are also clones with low rates of nut defects that directly affect the quality and economic value of hazelnut. In particular, the KF-42 clone stood out with its 97.2% good kernel rate. In addition, nut defects such as blank nut, shriveled kernel, twin kernel, abortive kernel, black tipped kernel, moldy kernel, and rotten kernel were not found in many clones during the examinations made during the study. In this respect, repeated studies under controlled conditions are important in order to make more precise judgments about the clones examined in terms of yield traits and nut defects, which are affected by many factors.

## Conflicts of interest

The authors declare no conflicts interest.

## Authorship contribution statement

SU: has contributed to the conceptualization, execution, fieldwork, laboratory analyses, data acquisition, analysis, interpretation, and writing of the article.

FB: has contributed to the planning and conceptualization of the study.

OK: has contributed to the fieldwork and laboratory analyses.

MFB: has contributed to the planning and conceptualization of the study.

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