Akademik Ziraat Dergisi 12(Özel Sayı): 71-84 (2023)
ISSN: 2147-6403 e-ISSN: 2618-5881 DOI: http://dx.doi.org/10.29278/azd.1273973

Araştırma (Research)

Grafting Success of Çakıldak Hazelnut Cultivar on *Corylus colurna* L. Seedling Rootstock in Spring and Summer Periods*

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*Bu makale birinci yazarın Yüksek Lisans Tezinden üretilmiştir.

Alınış tarihi: 30 Mart 2023, Kabul tarihi: 28 Eylül 2023
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Abstract

Objective: The objective of this study was to determine the grafting success of hazelnut on *Corylus colurna* L. seedling rootstock in the spring and summer periods in Ünye, Ordu.

Materials and Methods: The rootstock material was 2-3 years old *Corylus colurna* L. seedlings. The scion was Çakıldak (*Corylus avellana* L.) cultivar. For three years (2020-2022) in the spring, whip grafting on five different dates (4 April, 11 April, 18 April, 25 April and 2 May) and patch budding on three different dates (2 May, 9 May and 16 May) were applied under unheated high plastic tunnel conditions. Daily fresh scions and stored scions (SS) at 4°C were used for whip grafting. For two years (2020 and 2021), *Corylus colurna* L. seedlings were grafted with patch budding technique on 3 different dates (August 6, August 13 and August 20) under open field conditions. Graftings and buddings were made directly on the tubed seedlings.

Results: The success and shoot development in whip grafting and patch budding in the spring were significantly affected by grafting dates over three years. Whip graftings gave the most successful results using SS on April 4 (93.3%) and April 11 (86.6-93.3%) in 2020 and 2022. They developed shoots between 171.8 cm and 212.2 cm depending on year, grafting date and scion type. Patch buddings in the spring gave in the most successful results on 16 May 2020 (93.3%) and 16 May 2022 (83.3%). They developed shoots between 150 cm and 218, depending on year and grafting date. Patch buddings in summer resulted in the highest success on 20 August 2020 (93.6%) and 20 August 2021 (80%). Their shoot developments were between 206 cm and 228, depending on year and grafting date.

Conclusion: As a result, successful results were obtained from grafting trials of Çakıldak hazelnut cultivar on *Corylus colurna* L. rootstock in the spring and summer periods under Ünye ecological conditions. It has been evaluated that the data will contribute to the establishment of the hazelnut nursery sector and will shed light on future research.

Keywords: Hazelnut, *Corylus colurna* L., Çakıldak, whip grafting, patch budding

Çakıldak Fındık Çeşidinin *Corylus colurna* L. Çöğür Anacı Üzerinde İlkbahar ve Yaz Döneminde Aşıyla Çoğaltılması

Öz

Amaç: Bu çalışma, Ünye ekolojisinde ilkbahar ve yaz dönemlerinde *Corylus colurna* L. çöğür anacı üzerinde fındığın aşı başarısını belirlemek amacıyla yürütülmüştür.

Materyal ve Yöntem: Anaç materyali olarak 2-3 yaşlı *Corylus colurna* L. çöğürleri, kalem materyali olarak Çakıldak çeşidi kullanılmıştır. İlkbahar döneminde ısıtmasız yüksek plastik tünel koşullarında üç yıl (2020-2022) süreyle beş farklı tarihte (4 Nisan, 11 Nisan, 18 Nisan, 25 Nisan ve 2 Mayıs) dilcikli aşı ve üç farklı tarihte (2 Mayıs, 9 Mayıs ve 16 Mayıs) yama göz aşısı yapılmıştır. Dilcikli aşılarda günlük ve buzdolabında 4 ℃′ de bekletilmiş olmak iki farklı kalem tipi kullanılmıştır. İki yıl süreyle (2020-2021), *Corylus colurna* L. çöğürleri üzerine açık arazi koşullarında 3 farklı tarihte (6 Ağustos, 13 Ağustos ve 20 Ağustos) yama göz aşısı uygulanmıştır. Aşılar doğrudan tüplü çöğürler üzerine yapılmıştır.

Araştırma Bulguları: İlkbahar dönemi dilcikli ve yama göz aşısında aşı başarısı ve sürgün gelişimi üç yıl süreyle aşılama tarihlerinden önemli ($p<0.05$) derecede etkilenmiştir. 4°C'de depolanan aşı kalemleriyle yapılan dilcikli aşılar, 2020 ve 2022 yıllarında 4 Nisan (%93.3) ve 11 Nisan (%86.6-93.3) tarihlerinde en başarılı sonuçları vermiş, yıl, aşılama tarihi ve kalem tipine bağlı olarak 171.8 cm ile 212.2 cm arasında sürgün geliştirmişlerdir. İlkbahar dönemi yama gözü aşıları 16 Mayıs 2020 (%93.3) ve 16 Mayıs 2022 (%83.3) tarihlerinde en başarılı sonuçlara ulaşmış, yıl ve aşılama tarihine bağlı olarak 150 cm ile 218 cm arasında sürgün geliştirmişlerdir. Yaz dönemi yama göz aşıları ise en başarılı sonuçları 20 Ağustos 2020 (%93.6) ve 20 Ağustos 2021 (%80) tarihlerinde vermiş, yıl ve aşılama tarihine bağlı olarak 206 cm ile 228 cm arasında sürgün geliştirmişlerdir.

Sonuç: Ünye ekolojisinde *Corylus colurna* L. çöğürleri üzerine aşılı Çakıldak çeşidinin ilkbahar ve yaz dönemi aşılarından başarılı sonuçlar alınmıştır. Verilerin fındık fidancılık sektörüne katkı sağlayacağı ve sonraki araştırmalara ışık tutacağı değerlendirilmiştir.

Anahtar Kelimeler: Fındık, *Corylus colurna* L., Çakıldak, Dilcikli aşı, Yama göz aşısı

Introduction

Anatolia is among the homeland and natural spreading areas of hazelnut (*Corylus avellana* L.) (Özbek, 1978). Turkish hazelnut cultivars belong to the *Corylus avellana* L. species, and they tend to produce suckers (İslam, 2018; İslam, 2019; Figen et al., 2021). In Türkiye, hazelnut is traditionally grown in the form of a multi-stemmed bush. The propagation technique with suckers used for orchard establisment has many negative aspects and does not allow the mechanization required by modern hazelnut cultivation (Rovira, 2021).

Every year, sucker removal requires additional labor and cost. Application of herbicide several times a year for sucker removal adversely affects the environment and living things. Suckers can reduce the ventilation capacity of hazelnut plants and this may increase the epidemic of some diseases such as powdery mildew (Serdar et al., 2022). In addition, the supply of suckers by the growers can sometimes cause the cultivars to be mixed with each other, the establishment of orchards with mixed cultivars and types, and the failure to provide nut production standards at harvest. In this respect, the tendency to form sucker in hazelnut is seen as one of the important problems of cultivation and it is recommended to turn from multi-stem cultivation to single-stem cultivation (İslam, 2018; Karadeniz et al., 2019).

Hazelnut (*Corylus avellana* L.) can be propagated vegetatively by layering (Lagerstedt, 1983; Erdoğan ve Smith, 2005; Acı ve Beyhan, 2018), cutting (Ercişli ve Read, 2001; Özdemir ve Dumanoğlu, 2018), tissue culture (Nas and Read, 2004; Kaplan et al., 2020; Mardani et al., 2020) and grafting (Lagerstedt, 1981a; Balta, 1993; Achim et al., 2001; Cerovic et al., 2009; Şenyurt, 2017; Bijelic et al., 2021). Hazelnut layering is not practical because it requires a lot of manual labor, takes a long time and does not allow mass plant production in a short time (Janick and Moore, 1996). Although hazelnut tissue culture is more difficult than many tree species, requires expensive facilities and special expertise, it is used in the state of Oregon in the United States today and is increasingly used in many countries (Botta et al., 2019). It is possible to propagate by cuttings hazelnut plant, but the rooting level may vary depending on the cultivar, collection time, many treatments and environmental factors. Since stable results could not be obtained in obtaining cuttings with high rooting rate, which are suitable for orchard establishment, it has not yet found widespread use as a standard propagation method (Cristofori et al., 2010). Related researches show that grafting is a more suitable method for use in the modern hazelnut industry (Roversi, 2015). As it is known, grafting method in fruit trees offers important advantages such as benefiting from the characteristics of different rootstocks, fruiting trees at an earlier age, and obtaining high and quality products (Hartmann et al., 2011).

The purpose of the propagation by grafting the hazelnut plant is to grow cultivars on rootstocks that do not form suckers, in accordance with modern hazelnut cultivation (Kopuzoğlu and Şen, 1991). In order to affect the growing vigor of varieties, make the plant productive at an early age and reduce production costs, it is recommended to graft hazelnut plants on rootstocks that do not form suckers (Islam, 2019). Hazelnut cultivation in the form of single-stem trees allows mechanization and easy harvesting, and also increases yield (Mehlenbacher and Smith, 1992). Today, some nurseries in various countries produce hazelnut rootstocks and grafted hazelnut plants for commercial orchard establishment. There is increasing interest in cultivar/rootstock combinations in grafted hazelnut plants and it is expected that more new orchards will be established with grafted plants in the coming years (Rovira, 2021).

On the other hand, studies on hazelnut rootstocks have been limited so far. Various studies have been carried out on hazelnut rootstocks that do not form sucker. It has been reported that *Corylus colurna* L. genotypes are the most suitable rootstocks for hazelnut cultivars (Ninić-Todorović et al., 2009; Roversi, 2015; Karadeniz et al., 2019). The non-sucker feature gives this species the potential to be a rootstock for hazelnuts.

Hazelnut grafting is difficult due to slow formation of callus (Lagerstedt, 1984; Rahemi et al., 2016). Researches on hazelnut grafting have intensified in the United States and many European countries. In related studies, successful results were reported by applying various grafting methods and applications (Lagerstedt, 1981a; Lagerstedt, 1981b; Lagerstedt, 1983; Lagerstedt, 1984; Korac et al., 1997; Tous et al., 1997; Cerovic et al., 2009; Ninic-Todorovic et al., 2009; Ninic-Todorovic et al., 2012; Rovira et al., 2014). The aim of the study was to determine the success of hazelnut grafting on *Corylus colurna* L. seedling rootstocks under unheated high tunnel conditions in the spring and open field conditions in summer.

Material and Methods

Geographical location and climate of trial area

Ünye district of Ordu Province is located in the Central Black Sea region. Terme of Samsun Province is situated in the west of the district, Fatsa in the east, Kumru and Akkuş districts in the south and the Black Sea in the north. The district is located between 41° 07' 11'' north latitudes and 37° 16' 48' east longitudes. The soil structure of the central district is composed of alluvial, chestnut and brown forest soils (Kızılkan, 2017). The trial area, where the research was conducted, is at sea level in the center and is close to the Black Sea coast.

Table 1. Daily temperature and relative humidity ranges in Ünye in April, May, June, August, September and October (2020-2023) (Anonymous, 2022).

Temperature (°C)	Year	April	May	June	August	September	October
RDMIT (°C)	2020	5.1-10.6	8.8-17.6	14.3-21.6	17.6-24.3	17.8-23.0	14.4-19.5
	2021	3.8-12.3	6.9-16.2	13.4-23.4	18.5-23.7	12.3-22.7	9.1-17.1
	2022	5.7-14.5	8.2-17.7	16.2-20.3	-	-	-
RDMAT (°C)	2020	10.4-22.4	14.6-32.3	20.8-28.0	24.7-31.0	21.1-30.0	17.3-27.1
	2021	7.6-28	14.9-27.2	18.6-29.7	23.1-32.1	15-26.9	14.7-23.2
	2022	10.8-34.8	12.6-23.9	21.5-29.5	-	-	-
RDAT (°C)	2020	8.8-13.9	12.8-23.7	17.0-24.3	22.0-26.3	19.5-25.5	16.1-22.6
	2021	5.9-18.9	11.1-20.3	16.2-25.5	20.5-26.5	13.9-24	11.5-18.5
	2022	8.7-21.8	10.5-21.5	18.4-23.7	-	-	-
RDRH (%)	2020	63.4-90.1	57.8-92.8	64.9-90.4	61.5-85.9	71-90	-
	2021	69-95.5	64.6-95.1	72.6-94.9	72.9-97.0	60.7-99.0	-
	2022	33.0-100	53.0-99.3	59.4-94.6	-	-	-

RDMIT: Range of daily minimum temperature (°C), RDMAT: Range of daily maximum temperature (°C), RDAT: Range of daily average temperature (°C), RDRH: Range of daily relative humidity (%).

The climate structure of Ünye district reflects the typical Black Sea climate. The annual average temperature is 14.4°C and the annual precipitation is 1183 mm, and the coldest month of the year is February with 6.8°C. Average temperatures from April to September; April (10.9°C), May (15.1°C), June (20.1°C), July (23.2°C), August (28.3°C) and September (20.4°C) respectively (Kızılkan, 2017). The temperature and relative humidity values of the grafting period and the following, especially the first months, are very important for a successful graft union and graft survival (Balta, 1993). In this context, the daily minimum, maximum and average temperature ranges and relative humidity ranges for the periods in which hazelnut plants were grafted and the following months for three years (2020-2022) are given in Table 1, Figure 1, Figure 2 and Figure 3 (Anonymous, 2022).

Plant materials

In the study, the rootstock material was 2-3 years old *Corylus colurna* L. seedling rootstocks. One-year-old suckers, exposed to sunlight and free from diseases and pests, were collected from the ocaks (multi-stemmed bushes) of the Çakıldak (*Corylus avellana* L.) orchard established in the Kale neighborhood (altitude 200 m) of Ünye district (Ordu). The scions were prepared from one-year-old suckers.

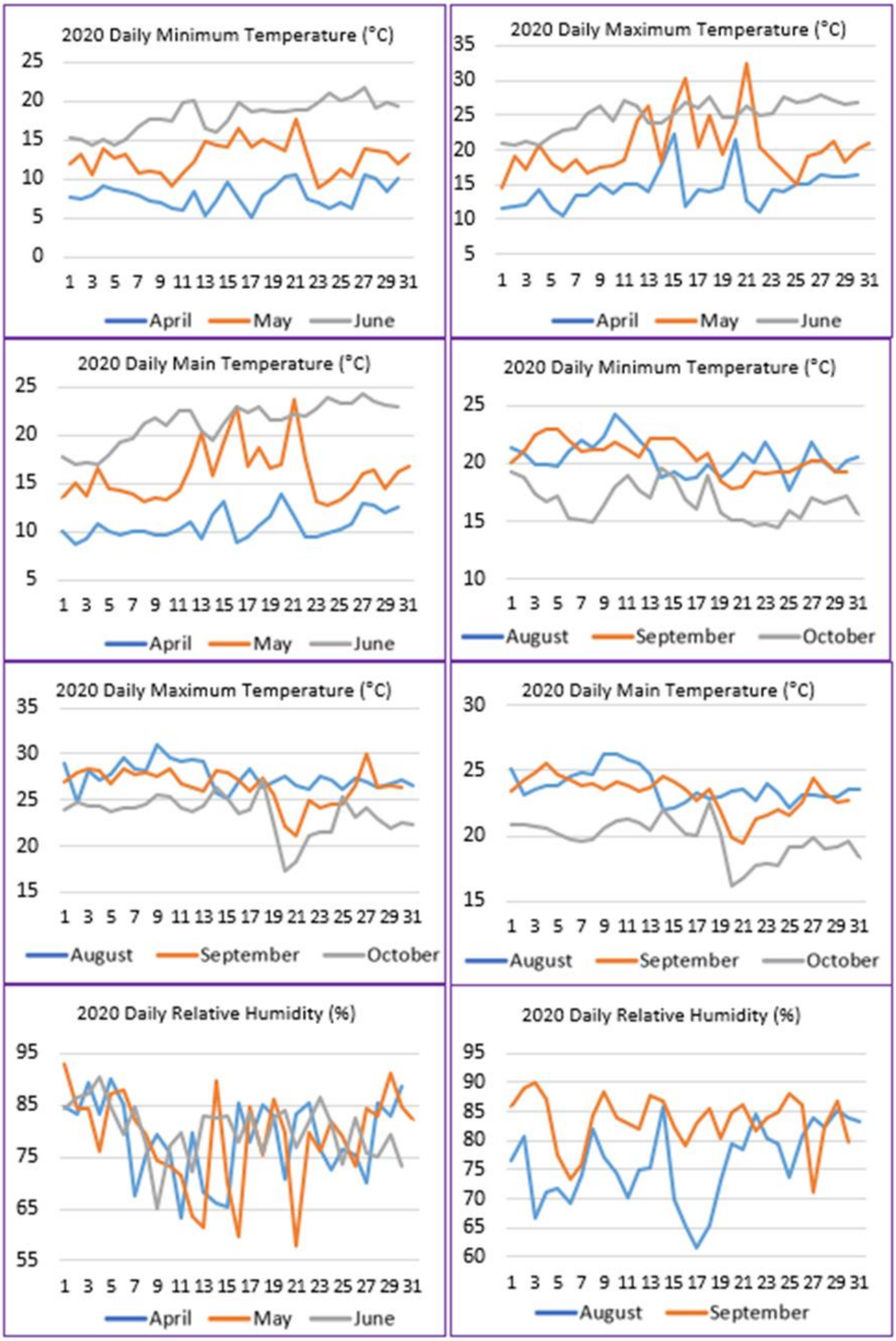

Figure 1. Changes in daily minimum, maximum and average temperatures and relative humidity between April-June and August-October in Ünye, Ordu (2020)

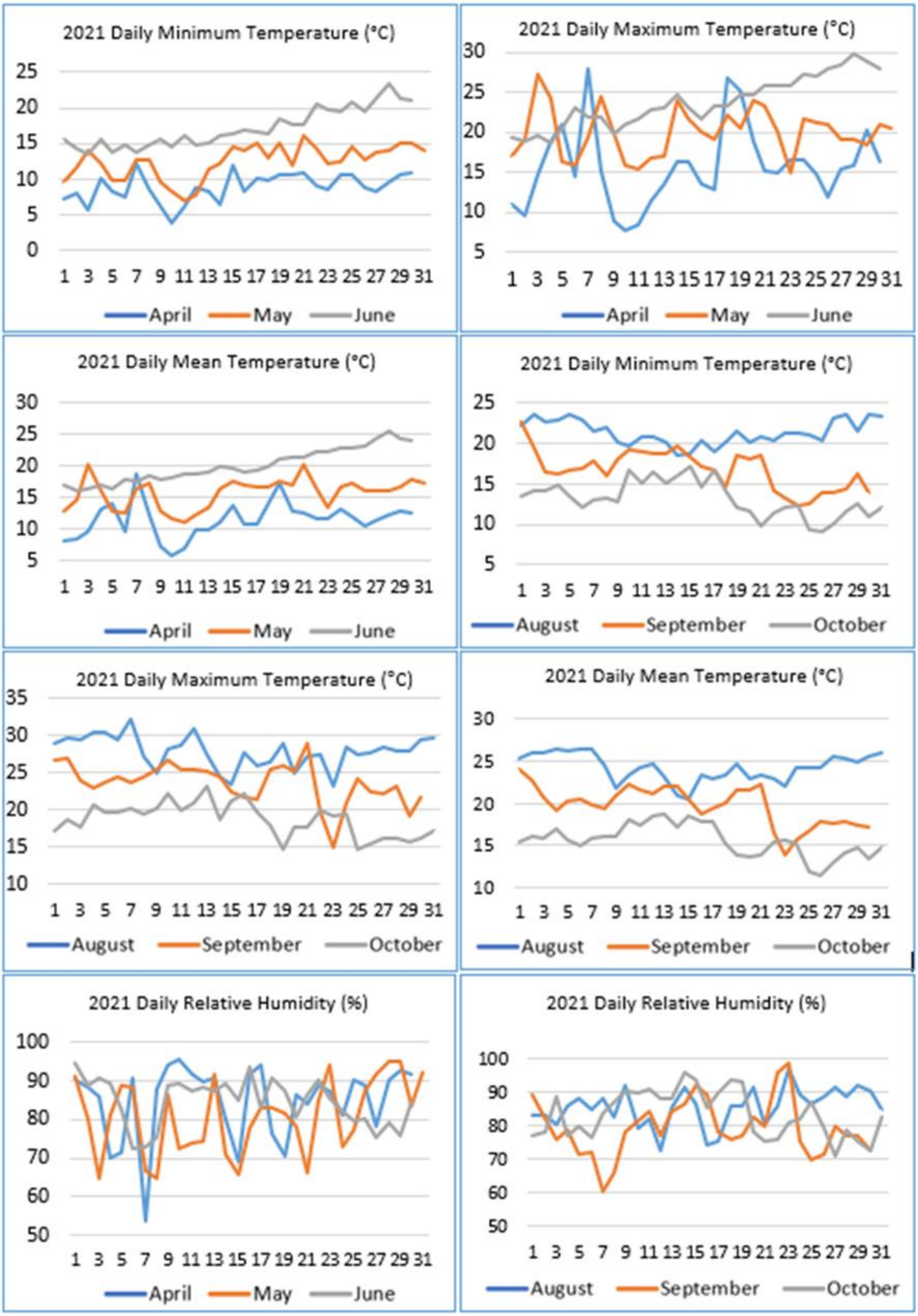

Figure 2. Changes in daily minimum, maximum and average temperatures and relative humidity between April-June and August-October in Ünye, Ordu (2021)

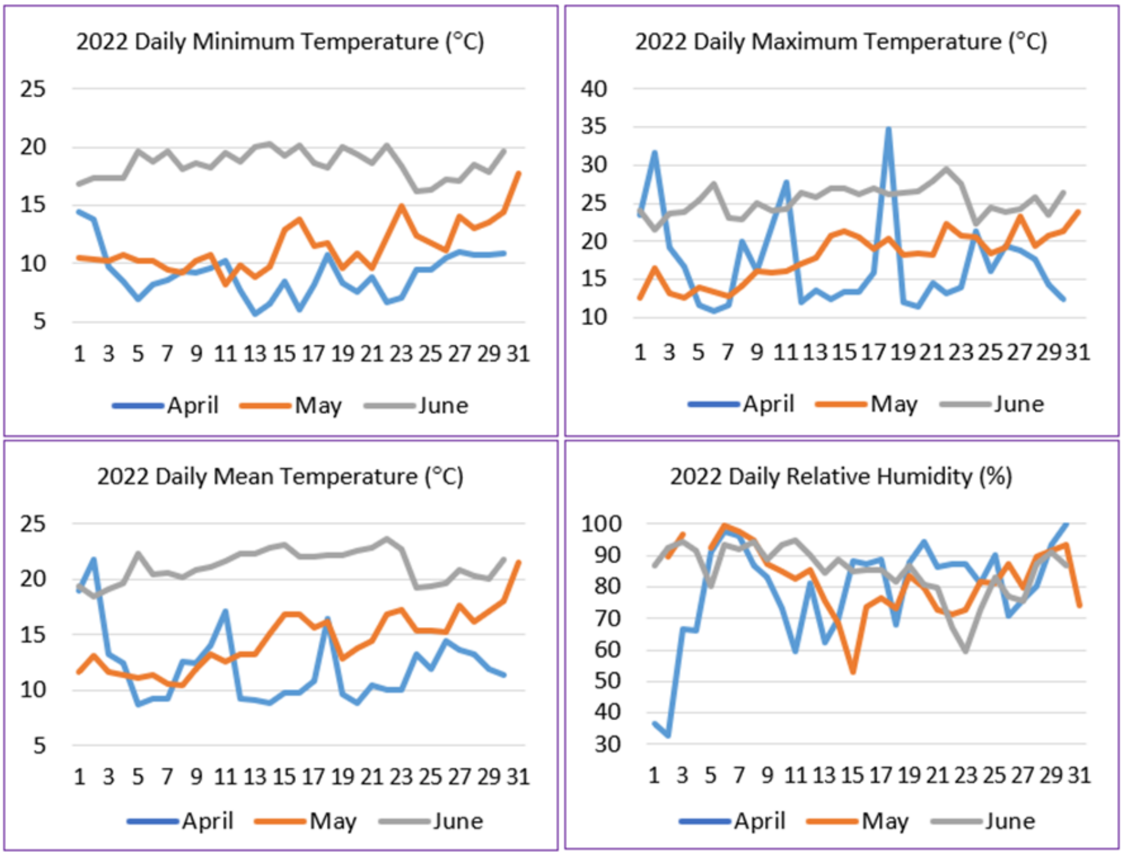

Figure 3. Changes in daily minimum, maximum and mean temperatures, and relative humidity between April-June in Ünye, Ordu (2022)

Method

Grafting in the spring

Turkish hazelnut (*Corylus colurna* L.) seedling rootstocks were placed in 2.5 liter black plastic tubes in autumn (November) and kept in an unheated high plastic tunnel (length 56 m, width 9 m and height 3.5 m) established at zero altitude until grafted in the spring. The mixture of soil, burnt animal manure, peat and mushroom compost (1:1:1:1) was used as the medium in the tubes. From about 2 weeks before the grafting date, they were regularly watered in the morning and evening every day. In order to prepare the scions, the sun-exposed, disease and pest-free annual suckers were cut from Çakıldak hazelnut cultivar ocaks (multi-stemmed bush) on the morning of the graft day in Kale neighborhood (altitude 200 m) of Ünye district. They were kept in a damp cloth to prevent moisture loss until grafted. Two types of scions were used for whip grafting, a daily cut fresh scion and scion kept in the refrigerator at 4°C (approximately 1.5 to 2.5 months depending on grafting date). For three years (2020, 2021 and 2022), *Corylus colurna* L. seedling rootstocks were grafted with whip grafting (Figure 4) on 5 different dates (April 4, April 11, April 18, April 25 and May 2) and patch budding (Figure 5) techniques on 3 different dates (2 May, 9 May and 16 May) under unheated high plastic tunnel conditions in the spring. Whip grafting was made directly on the seedling in the tube. Silicone band was used to wrap the grafts. The grafting bands were removed 6 weeks after grafting. Whip grafts were kept in high plastic tunnel until September, then left to develop under outdoor conditions. The high plastic tunnel was regularly ventilated and the grafted plants were carefully cared for.

Grafting in summer

Turkish hazelnut (*Corylus colurna* L.) seedling rootstocks were placed in 2.5 liter black plastic tubes in autumn (November) and kept in an unheated high plastic tunnel until mid-May. They were then transferred to outdoor conditions and allowed to develop until grafting in August. The mixture of soil, burnt animal manure, peat and mushroom compost (1:1:1:1) was used as the medium in the tubes. Annual suckers were cut from Çakıldak hazelnut cultivar ocaks on the morning of the graft day in Kale neighborhood of Ünye district. They were kept in a damp cloth to prevent moisture loss until grafted. For two years (2020 and 2021), *Corylus colurna* L. seedling rootstocks were grafted with patch budding technique on 3 different dates (August 6, August 13 and August 20) under open field conditions. Patch budding was made directly on the seedling in the tube. Silicone band was used to wrap the grafts. The grafting bands were removed 6 weeks after grafting. Patch buddings, which were placed in a high plastic tunnel to protect them from the cold at the beginning of November, were transferred to field conditions for their development at the end of April after overwintering. Their care were carefully followed.

Figure 4. Patch budding on C. *colurna* L.

Figure 5. Whip grafting on C. *colurna* L.

Recorded data

Data on grafting success (%), shoot length and diameter of grafted plant (cm), rootstock diameter (mm) and height of grafted plant were recorded. Rootstock diameter (mm) was determined by measuring the stem thickness just above the soil level of the plant. Shoot diameter of grafted plant was measured just above graft union. Data on whip grafting and patch budding performed in the spring were recorded on 15 November each year (approximately 6.5-7.5 months after grafting). Data on patch budding in August were recorded on 25 October the following year (approximately 14 months after budding). In the research, grafting or budding success (%) also refers to the survival rate (%) of grafted or budded plants.

Statistical analysis

The research was carried out according to a completely randomized design with three replicates. The data were analyzed with one-way analysis of variance (ANOVA) using the statistical package programs JMP 14.0 and Minitab 17. Statistical differences between the mean values were determined at the 5% significance level by the LSD multiple comparison method. The study was conducted with a total of 1590 grafts over three years (2020-2022). The number of grafted hazelnut plant was 900 for whip grafting and 270 for patch budding in the spring, and 420 for patch budding in summer.

Results

Whip grafting in the spring

In the spring, whip grafting was made under unheated high plastic tunnel conditions. The grafting success, shoot length and diameter of grafted plant, rootstock diameter and height of grafted plant differed significantly ($p<0.05$) depending on grafting dates each year. Grafting success varied between 33.3% and 83.3% in 2020, 26.6% and 73.3% in 2021, and 20% and 80% in 2022 using DS. It was between 53.3% and 93.3% in 2000, 43.3% and 80% in 2021, and 53.3% and 93.3% in 2022 using SS. The highest success with SS was obtained from whip grafts dated April 4 (93.3%) in 2020 and 2022, and April 11 (80%) in 2021. The highest success with DS was taken from whip grafts dated April 11 (83.3%) in 2020, April 11 (73.3%) in 2021 and April 4 (80%) in 2022 (Table 2). Shoot lengths of whip graftings were measured between 164-179 cm in 2020, 192-239 cm, and 186-216 cm in 2022 using DS. They were between 166-179 cm in 2020, 191-214 cm in 2021, and 193-215 cm in 2022 with SS. Shoot diameters of grafted plants were between 12-14.4 mm in 2020, 8-9.8 mm and 8.6-10.1 mm using DS. They were between 11.5-13.3 mm in 2020, 6.6-8 mm in 2021 and 8.5-11.5 mm in 2022 with SS (Table 3). Rootstock diameter ranged from 11.3 mm to 16.4 mm. The height of grafted plant was measured between 195 cm and 279 cm depending on scion types and years (Table 4).

Patch budding in the spring

In the spring, patch budding was made under unheated high plastic tunnel conditions.

Table 2. The success of hazelnut whip grafting on *Corylus colurna* L. seedling rootstock under unheated high plastic tunnel conditions in the spring in Ünye, Ordu (2020-2022).

Date	Scion	Number of grafted plant			Grafting success (%)		
		2020	2021	2022	2020	2021	2022
4 April	SS	30	30	30	93.3 a	70.0 abc	93.3 a
	DS	30	30	30	80.0 bc	73.3 ab	80.0 bc
11 April	SS	30	30	30	93.3 a	80.0 a	86.6 ab
	DS	30	30	30	83.3 abc	66.6 bc	70.0 cde
18 April	SS	30	30	30	86.6 ab	66.6 bc	73.3 cd
	DS	30	30	30	80.0 bc	60.0 cd	60.0 ef
25 April	SS	30	30	30	73.3 c	53.3 de	53.3 fg
	DS	30	30	30	60.0 d	46.6 e	46.6 g
2 May	SS	30	30	30	53.3 d	43.3 e	66.6 de
	DS	30	30	30	33.3 e	26.6 f	20.0 h
Mean	SS				80.0	62.6	74.6
	DS				67.3	54.6	55.3
Significance					***	***	***
LSD (0.05)					11.6	10.9	10.8

DS: Daily fresh scion, SS: Scion stored at 4°C
The differences between mean values shown on the same line with the same letter are not significant ($p<0.05$)

Table 3. Shoot development in hazelnut whip grafting on *Corylus colurna* L. seedling rootstock under unheated high plastic tunnel conditions in the spring in Ünye, Ordu (2020-2022).

Date	Scion	Shoot length of grafted plant (cm)			Shoot diameter of grafted plant (mm)		
		2020	**2021**	**2022**	**2020**	**2021**	**2022**
4 April	SS	171 a-d	209 c	211 ab	12.1 d	6.6 e	11.5 a
	DS	165 cd	239 a	216 a	12.0 d	8.0 d	10.1 b
11 April	SS	179 a	214 c	215 a	13.0 c	8.0 d	10.6 b
	DS	175 abc	220 b	208 bc	13.7 b	9.8 a	8.6 c
18 April	SS	179 a	200 d	204 c	13.3 bc	7.8 d	8.8 c
	DS	179 a	209 c	194 d	14.4 a	8.6 c	8.8 c
25 April	SS	166 bcd	198 d	203 c	11.5 d	7.5 d	8.7 c
	DS	164 d	201 d	189 de	12.9 c	9.8 a	9.0 c
2 May	SS	177 ab	191 e	193 d	13.3 bc	7.5 d	8.5 c
	DS	176 ab	192 e	186 e	13.0 c	9.2 b	8.6 c
Mean	SS	174.4	202.4	205.2	12.6	7.5	9.6
	DS	171.8	212.2	198.6	13.2	9.1	9.0
Significance		*	***	***	***	***	***
LSD (0.05)		11.4	5.9	5.3	0.62	0.53	0.64

DS: Daily fresh scion, SS: Scion stored at 4°C
The differences between mean values shown on the same line with the same letter are not significant ($p<0.05$)

Table 4. Rootstock diameter and height of grafted plant in hazelnut whip grafting on *Corylus colurna* L. seedling rootstock under unheated high plastic tunnel conditions in the spring in Ünye, Ordu (2020-2022).

Date	Scion	Rootstock diameter (mm)			Height of grafted plant (cm)		
		2020	**2021**	**2022**	**2020**	**2021**	**2022**
4 April	SS	13.8 bc	11.4 de	14.3 b	216 abc	246 e	258 ab
	DS	14.0 bc	12.7 b	15.1 a	195 d	279 a	271 a
11 April	SS	13.7 c	11.3 e	14.3 b	224 a	247 de	265 ab
	DS	15.9 a	13.8 a	14.8 ab	217 ab	277 ab	252 bc
18 April	SS	13.7 c	11.5 cde	14.4 b	224 a	249 de	254 bc
	DS	16.4 a	13.1 b	14.8 ab	209 bc	267 bc	230 de
25 April	SS	12.2 d	11.9 c	14.7 ab	211 bc	251 de	243 cd
	DS	14.5 bc	11.7 cd	14.5 b	203 cd	258 cd	234 de
2 May	SS	14.6 b	12.0 c	14.3 b	217 ab	232 f	232 de
	DS	14.6 b	12.8 b	14.7 ab	208 bcd	257 cde	226 e
Mean	SS	13.6	11.6	14.4	218.4	245.0	250.4
	DS	15.1	12.8	14.8	206.4	267.6	242.6
Significance		***	***	*	**	***	***
LSD (0.05)		0.81	0.50	0.59	13.2	11.2	13.4

DS: Daily fresh scion, SS: Scion stored at 4°C
The differences between mean values shown on the same line with the same letter are not significant ($p<0.05$)

The grafting success, shoot length and diameter of grafted plant, rootstock diameter (except 2021 data) and height of grafted plant differed significantly (p<0.05) depending on grafting dates each year. The success of patch budding ranged from 60% (May 2) to 93.3% (May 16) in 2020, from 46.6% (May 2) to 90.0% (May 16) in 2021, and from 60.0% (May 2) to 83.3% (May 16) in 2022. The highest success was obtained from the patch buddings dated May 16 in 2020, 2021 and 2022 (Table 5). Patch buddings with DS developed shoots of 150-216 cm in 2020, 154-164 cm in 2021, and 186-218 cm in 2022. Their shoot diameters were measured between 9.6-10.6 mm in 2020, 8.2-9.7 mm in 2021 and 8.1-8.8 mm in 2022 (Table 6). Rootstock diameter ranged from 12 mm to 15.1 mm. The height of grafted plant was recorded between 190 cm and 256 cm depending on scion types and years (Table 7).

Table 5. The success of hazelnut patch budding on *Corylus colurna* L. seedling rootstock under unheated high plastic tunnel conditions in the spring in Ünye, Ordu (2020-2022).

Date	Number of grafted plant			Grafting success (%)		
	2020	2021	2022	2020	2021	2022
2 May	30	30	30	60.0 b	46.6 b	60.0 b
9 May	30	30	30	86.6 a	80.0 a	73.3 ab
16 May	30	30	30	93.3 a	90.0 a	83.3 a
Mean				79.9	72.2	72.2
Significance				**	***	*
LSD (0.05)				11.0	12.5	17.0

The differences between mean values shown on the same line with the same letter are not significant (p<0.05)

Table 6. Shoot development in hazelnut patch budding on *Corylus colurna* L. seedling rootstock under unheated high plastic tunnel conditions in the spring in Ünye, Ordu (2020-2022).

Date	Shoot length of grafted plant (cm)			Shoot diameter of grafted plant (mm)		
	2020	2021	2022	2020	2021	2022
2 May	150 b	164 a	218 a	9.6 b	9.2 ab	8.1 b
9 May	152 b	155 b	196 b	10.6 a	8.2 b	8.2 ab
16 May	216 a	154 b	186 c	10.1 ab	9.7 a	8.8 a
Mean	172.6	157.6	200	10.1	9.0	8.4
Significance	***	**	***	*	*	*
LSD (0.05)	7.0	5.5	9.6	0.79	1.26	0.61

The differences between mean values shown on the same line with the same letter are not significant (p<0.05)

Table 7. Rootstock diameter and height of grafted plant in hazelnut patch budding on *Corylus colurna* L. seedling rootstocks under unheated high plastic tunnel conditions in the spring in Ünye, Ordu (2020-2022).

Date	Rootstock diameter (mm)			Height of grafted plant (cm)		
	2020	2021	2022	2020	2021	2022
2 May	12.0 c	12.4 a	14.8 a	191 b	207 a	255 a
9 May	14.3 b	12.9 a	14.9 a	193 b	217 a	234 b
16 May	15.1 a	13.3 a	14.5 b	256 a	190 b	231 b
Mean	13.8	12.9	14.7	213.3	204.6	240
Significance	***	NS	*	***	**	***
LSD (0.05)	0.61	1.01	0.35	7.1	14.1	3.8

The differences between mean values shown on the same line with the same letter are not significant (p<0.05)
NS: Non-significance

Patch budding in summer

In summer, patch budding was made under open field conditions in August. Grafting success, shoot length of grafted plant and rootstock diameter in patch budded plants in August 2020 differed significantly (p<0.05) depending on budding dates. Grafting success and rootstock diameter in patch budded plants in August 2021 differed significantly (p<0.05) depending on budding dates. The patch budding success varied between 66.3% (August 6) and 93.6% (August 20) in 2020, and 43.3% (August 6) and 80.0% (August 20) in 2021. Therefore, the highest success was obtained from the patch buddings dated August 20 in 2020 and 2021. Patch budded plants developed shoots of 206-228 cm in 2021 and 214-222 cm in 2022. Their shoot diameters were recorded between 10.9-11.5 mm in 2020 and 11.4-12.0 mm in 2021. In 2021, their shoot lengths and diameters were computed statistically indifferent depending on budding date (Table 8 and Table 9).

Table 8. Grafting success, shoot length and diameter of grafted plant, and rootstock diameter in hazelnut patch budding on *Corylus colurna* L. seedling rootstocks under open field conditions in sommer in Ünye, Ordu (2020).

Date	Number of grafted plant	Grafting success (%)	Shoot length of grafted plant (cm)	Shoot diameter of grafted plant (mm)	Rootstock diameter (mm)
6 August	110	66.3 c	228 a	11.5 a	16.6 a
13 August	110	80.9 b	213 ab	11.1 a	15.5 a
20 August	110	93.6 a	206 b	10.9 a	14.4 b
Mean		80.3	215.6	11.2	15.5
Significance		***	*	NS	**
LSD (0.05)		5.8	18.1	0.54	0.33

The differences between mean values shown on the same line with the same letter are not significant (p<0.05)
NS: Non-significance

Table 9. Grafting success, shoot length and diameter of grafted plant, and rootstock diameter in hazelnut patch budding on *Corylus colurna* L. seedling rootstocks under open field conditions in sommer in Ünye, Ordu (2021).

Date	Number of grafted plant	Grafting success (%)	Shoot length of grafted plant (cm)	Shoot diameter of grafted plant (mm)	Rootstock diameter (mm)
6 August	30	43.3 b	222 a	12.0 a	12.8 b
13 August	30	56.6 b	214 a	11.4 a	14.6 a
20 August	30	80.0 a	218 a	11.5 a	14.1 a
Mean		60.0	218	11.6	13.8
Significance		**	NS	NS	*
LSD (0.05)		16.3	7.6	1.16	1.07

The differences between mean values shown on the same line with the same letter are not significant (p<0.05)
NS: Non-significance

Discussion

A limited number of studies have been carried out in our country on the propagation of hazelnut by grafting. The studies have been mostly concentrated in the USA and some European countries. In related studies, grafting success rates have been reported depending on grafting techniques, grafting time and conditions, varieties and many applications. Pathak et al. (1978) achieved a graft success rate of 80% with whip and split grafting techniques, 75% with chip budding, 65% with patch budding, and 45% with T-budding techniques. They reported that shoot growth was more vigorous in budding than in grafting. Me et al. (1981) grafted Negret cultivar on 3-year-old Tonda Gentile Della Langhe rootstock. They obtained 54% grafting success with dormant budding, and 62-83% with whip grafting in January in the greenhouse, and reported that the maximum shoot growth was 160 cm in dormant budding.

It has been reported that over 90% success rate was achieved from dormant season hazelnut grafts that were callused at 27°C for 28 days and then transferred to appropriate conditions (Lagerstedt, 1981a; Lagerstedt, 1981b; Yarris and Lagerstedt, 1981; Lagerstedt, 1983); Lagerstedt, 1984). Lagerstedt (1981b) stated that the hazelnut grafts on the hot callusing device formed a satisfactory callus within 21-28 days at 27°C and did not require greenhouse facilities after grafting, while in the January-April period grafting success was between 77% and 100%. The researcher, who also examined the effects of different binding materials, determined 93% graft success in Johnson' cultivar grafted on Daviana rootstock with black plastic material, 84% success in Johnson cultivar grafted on Barcelona rootstock, and 27% in budding under nursery conditions. In Australia, Thomson (1984) grafted with whip grafting technique Kentish Cob hazelnut cultivar on White avellana rootstock in winter, spring and summer periods, and then callused for 4 weeks at 27°C in a hot callusing device. He reported the highest success (93%) in winter (June) and the lowest success (10-43%) in spring and summer periods.

In a study conducted in Samsun, three hazelnut cultivars were grafted onto suckers of Çakıldak cultivar with splice grafting technique on 11 November, 2 December and 23 December and kept under controlled conditions for one month. The highest success (91.2-97.5%) was obtained on 23 December, and the lowest success (58.7-62.5%) was taken on 11 November. However, after transferring to the nursery plot, survival rates of grafted plants decreased to 1.2-26.2% as of the end of May (Kopuzoğlu, 1988). Balta (1993) recorded the success rates of hazelnut grafting in December, January and

February as 91.1% for chip budding, 85.0% for whip grafting and 81.7% for splice grafting. Hazelnut grafting success in the dormant period were reported as 0.0-82.2% (Duyar et al., 2014) and 30.1-86% (Şenyurt, 2017) with patch budding, whip and splice grafting techniques on *Corylus colurna* L. seedling rootstocks.

In Romania, the highest success with Valcea 22, White Lambert and Hall's Giant hazelnut cultivars was recorded in chip budding (68.7%) on June 15 (68.7%), hot-callused whip and splice graftings (86.8%) and cleft grafting (95.7%) (Achim et al., 2001). In Romania, Achim et al. (2001) reported the highest success with Valcea 22, White Lambert and Hall's Giant hazelnut cultivars in chip budding (68.7%) on June 15 (68.7%). They noted that the success rates of hot-callused whip and cleft grafts, which they performed in winter, were 86.8% and 95.7%, respectively. In Serbia, Cerović et al. (2009) determined the highest success in Tonda Gentile Romana (94.6%) and the lowest success (72.6%) in Halls Giant by using whip grafting on two-year-old Corylus colurna L. rootstocks. Bijelic et al. (2021) achieved a success rate of 65.5-85.8% in 2020 and 61.3-85.2% in 2021 with whip and splice grafting on two-year-old Corylus colurna L. seedling rootstocks in the spring. They reported shoot growth of 166-184 cm in 2020 and 170-189 cm in 2021 for grafted plants. Ninic-Todorovic et al. (2012) obtained the highest success (92.6%) in Tonda Gentile Romana cultivar grafted on B9 rootstock (Corylus colurna L.) and the lowest success (53.10%) in Atropurpurea cultivar grafted on A1 rootstock (Corylus colurna L.) using whip grafting in April. In Canada, Rahemi et al. (2016) reported the hypocotyl cleft graft as a simple method to increase the success rate of hazelnut grafting when the scion is coated with a thin layer of paraffin (wax). They grafted Carmela cultivar (*C. avellana*) on etiolated hypocotyls of native hazelnuts (*C. americana*), and obtained the success rate of 9% from uncoated scions and 85% from coated scions with a thin layer of paraffin after grafting.

The studies mentioned above show that the grafting success in hazelnut varies according to grafting technique, rootstock, cultivar, grafting time and conditions, and that high success can be achieved by using many grafting techniques at appropriate times and conditions. The findings of this study, indicating high success rates, were consistent with those of many investigators (Me et al., 1981; Lagerstedt, 1981a; Lagerstedt, 1981b; Lagerstedt, 1983; Lagerstedt, 1984; Thomson, 1984; Achim et al., 2001; Cerović et al., 2009) Ninic-Todorovic et al., 2012; Şenyurt, 2017; Bijelic et al., 2021).

In this study, whip grafts performed in the spring gave the most successful results using SS on April 4 (93.3%) and April 11 (86.6-93.3%) in 2020 and 2022. They developed shoots between 171.8 cm and 212.2 cm depending on year, grafting date and scion type. Patch buddings in the spring resulted in the most successful results on 16 May 2020 (93.3%) and 16 May 2022 (83.3%), and also developed shoots between 150 cm and 218, depending on year and grafting date. Patch buddings in summer resulted in the most successful results on 20 August 2020 (93.6%) and 20 August 2021 (80%). Their shoot developments were between 206 cm and 228, depending on year and grafting date. In this study, especially successful results above 90% were found remarkable. Grafted hazelnut plants continued their development under field conditions in Ünye, Ordu (Figure 6).

Figure 6. Grafted hazelnut plants that continue their development in field conditions

Conclusion

As a result, successful results were obtained from grafting and budding trials of Çakıldak hazelnut cultivar on *Corylus colurna* L. seedling rootstock in spring and summer periods under Ünye (Ordu) ecological conditions. Whip grafts in spring had the highest success percentages using SS on April 4 (93.3%) in 2020 and 2022, and on April 11 (93.3%) in 2020. Patch buddings in spring had the most successful results (93.3%) on 16 May 2020. Patch buddings in summer resulted in the highest success rates (93.6%) on 20 August 2020. Some of whip-grafted, patch budded and chip-budded plants developed shoots higher than 2 m, depending on years and grafting dates. It has been evaluated that the data will contribute to the hazelnut nursery sector in our country and will shed light on future research.

Conflicts of interest

The authors declare no conflicts of interest.

Authors' Contributions

BDA: Contributed to the planning and execution of the research, the procurement of materials, grafting and the collection of data.

FB: Contributed to the planning of the research, the procurement of materials, the evaluation of the findings and the writing of the article.

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