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Determination of the Dormancy and Active Growth Duration of Various Rootstock and Cultivar Combinations of Pear Trees along Their Phenological Stages

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ABSTRACT

This research was performed to clarify dormancy and active growth durations along with the phenological stages of 'Santa Maria', 'Williams', and 'Deveci' cultivars on eight rootstocks, including two Quince clonal rootstocks (BA29 and QA), five pear clonal rootstocks (FOX9, FOX11, OHxF333, OHxF87, and FAROLD40), and pear seedling rootstock during 2021 and 2022. It has been determined that the phenological stages start earlier in 2022; on the contrary, the active growth period ended earlier in 2021 (20 November) than in 2022 (29 November). In the case of the three combination effects of years x rootstocks x cultivars (Y x R x C) on the active growth duration (AGD), the results were obtained in the range of 187.0–228.4 days. The AGD was determined to be the lowest (187.0 days) in the 'Santa Maria'/FOX9 combination in the year 2021, while the highest (228.4 days) in the 'Deveci'/FOX11 combination in the research year 2022. Considering the main effect of rootstocks (R) on the dormancy duration (DD), the obtained results varied between 148.7 and 153.7 days. The DD was found to be the lowest (148.7 days) on the FOX11 rootstock, while the highest (153.7 days) on the BA29 and FOX9 rootstocks. Understanding the AGD and DD of fruit trees is a critical approach for the ideal management of fruit orchards scientifically and effectively. Finally, it can be advised to use cultivars with rootstocks that show lower AGD in humid temperate regions; they will be more suitable for mitigating the adverse effects of stress factors.

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Armut Ağaçlarının Farklı Anaç ve Çeşit Kombinasyonlarının Dormansi ve Aktif Büyüme Süreleri ile Fenolojik Safhalarının Belirlenmesi

ÖZET

Bu araştırma iki ayva klon anacı (BA29 ve QA) ile beş armut klon anacı (FOX9, FOX11, OHxF333, OHxF87 ve FAROLD40) ve armut çöğür anaçları üzerine aşılanmış 'Santa Maria', 'Williams' ve 'Deveci' armut çeşitlerinin fenolojik dönemleri ile birlikte dormansi ve aktif büyüme sürelerini aydınlatmak amacıyla 2021 ve 2022 yıllarında yapılmıştır. Fenolojik evrelerin 2022'de daha erken başladığı belirlenirken aktif büyüme döneminin 2021'de (20 Kasım) 2022'den (29 Kasım) daha erken sona erdiği görülmüştür. Aktif büyüme süresi (AGD) üzerine yıl x anaç x çeşit (Y x R x C) interaksiyonu etkisine bakıldığında, sonuçlar 187.0 - 228.4 gün aralığında olduğu tespit edilmiştir. AGD, 2021 araştırma yılında 'Santa Maria'/FOX9 kombinasyonunda en düşük (187,0 gün), 2022 araştırma yılında 'Deveci'/FOX11 kombinasyonunda en yüksek (228,4 gün) olarak belirlenmiştir. Anaçların (R) dinlenme süresi (DD) üzerindeki ana etkisi dikkate alındığında, elde edilen sonuçlar 148.7 - 153.7 gün arasında değişmiştir. En düşük DD (148,7 gün) FOX11 anacında, en yüksek (153,7 gün) BA29 ve FOX9 anacında bulunmuştur. Meyve ağaçlarının AGD ve DD'sini anlamak, meyve bahçelerinin bilimsel ve etkili bir şekilde ideal yönetimi için kritik bir yaklaşımdır. Sonuç

Bahçe Bitkileri

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Pyrus communis

olarak, stres faktörlerinin olumsuz etkilerini azaltmak için nemli ılıman bölgelerde daha düşük AGD gösteren anaç ve çeşitlerin kullanılması tavsiye edilebilir.

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INTRODUCTION

After apples, pears are among the most popularly produced and eaten pome fruits across the globe. One of the most significant pear species in terms of fruit production approaches is *Pyrus communis* L. (Öztürk & Faizi, 2022). Lower buds develop on terminal branches and short spurs that are two or more years old, and floral initiation in pear trees takes place approximately 60 days after full flowering. Most pear cultivars typically flower each year. The indeterminate pear inflorescence (corymb), which has 7–8 blooms, is composed of lateral blossoms that open first and terminal blossoms that open last. Pear flowers typically have five petals, five sepals, 20 to 30 stamens, most of which have red anthers, two to five freestyles closely attached at the base, and an ovary with five locules and two ovules in each (Mumtaz et al., 2020). Pear trees are less cold-resistant than apple trees but more robust to heat and drought. Early spring frosts restrict pear cultivation. Pears can resist temperatures of up to -30 °C; however, prolonged exposure to cold damages the shoot tips. At -2.2 °C, pear blooms are damaged, whereas small fruits are damaged at 1.1 °C (Kurt et al., 2022). Appropriate ecology is an important factor in obtaining optimum vegetative and generative development from fruit trees, and it will determine whether the cultivars can or can't complete their phenological stages (Pasa et al., 2015; Hepaksoy, 2019). The timing of appropriate management actions, such as training, pruning, watering, fertilizing, diseases, insect control, selection of appropriate pollinizers, etc., depends on studying fruit tree phenology. A deciduous fruit tree's phenology describes the periodic biological processes that occur from the dormant stage through fruit production and are closely influenced by seasonal and climatic changes. Pear trees go through eight phenological phases: dormancy, swelling bud, budburst, green bud, white bud, bloom, petal fall, and fruit set. Fruit buds are largely latent at the dormant stage. Fruit buds begin to swell, exposing patches of lighter-colored tissue and dividing layers. Then, the budburst occurs, exhibiting the blossom buds' tips. In the cluster with the elongated stem, after a few days following the budburst, green bloom buds first develop before changing to white blossom buds. The blossom buds open at last, setting the stage for the subsequent flower petal and fruit fall. The cell division stage of a pear tree lasts for 25–30 days after blooming in early-maturing varieties and 45 days in late-maturing varieties. The fruit expansion stage occurs in the final month or two months before harvest. Between cell division and the expansion of fruits, the pear fruit slowly enlarges (Atreya et al., 2021). Based on previous phenological stage studies, pear trees started to flower earlier after 1982 as a result of changes in air temperature and frost days. This change in flowering phenology is anticipated to persist under projected future climatic conditions. Monitoring changes in the flowering period is essential because earlier flowering and budburst could cause phenological mismatches between pollen receiver trees and pollinators, modify agricultural spraying schedules, increase the risk of frost exposure, and amplify the effects of insect populations within an agroecosystem (Reeves et al., 2022). The flowering time is a crucial phenological occurrence for trees; the exact date of this event can change the likelihood of effective pollination, affecting fruit set and production. Numerous studies emphasize temperature as the primary determinant affecting flowering phenology; other weather factors, such as frost days, rainfall, relative humidity, and solar radiation, also affect the phenological stages of pear trees (Drepper et al., 2020; Reeves et al., 2022). These crops enter a dormant stage throughout the winter, a time of limited growth that guards them against chilly temperatures and frost damage. While forcing times for pears are typically from January to April, cooling times are often between October and December (Drepper et al., 2020). In temperate fruit trees, flowering is influenced by the temperatures in the previous months; chilling is needed to break endodormancy, and subsequently, exposure to heat is required. These cultivar-specific agroclimatic conditions govern each cultivar's capacity to adapt to the growing region and variations in the climate. Temperatures during the chilling phase were a major factor in determining flowering dates. This suggests that flowering delays or even improper blooming could result from many places' decreased winter chill brought on by worldwide warming (Fadon et al., 2023). But always, there is no significant correlation between the temperature, relative humidity, and

radiation with the phenological stages, including the flowering date of pear trees as observed in the tropical semi-arid conditions of Brazil (Oliveira et al., 2017). Dormancy, defined by the absence of discernible growth, enables fruit trees to survive in the cold winter months. Three distinct stages are commonly used to describe dormancy. First and foremost, before winter, the freshly developed buds' ability to grow is constrained by the effects of other plant features. Secondly, the development capacity is reasonably restricted during the winter (ecodormancy). Finally, for growth to resume and eventually lead to flowering, warm temperatures are required (endodormancy) (Atreya et al., 2021; Fadon et al., 2023). The dormancy of the European pear has not been extensively studied. To identify biomarkers that aid in defining the dormancy stages and calculating the agroclimatic needs of cultivars, more study on dormancy in the European pear is required (Martinez-Nicolas et al., 2016). Under the ecological conditions of Samsun Province, research that explains the phenological phases in various combinations of rootstocks and cultivars has not yet been available. Due to that, this research was performed to clarify dormancy and active growth duration along with the phenological stages of 'Santa Maria', 'Williams', and 'Deveci' cultivars on eight different rootstocks during 2021 and 2022.

MATERIALS and METHODS

Materials

In the experiment 'Santa Maria', 'Williams' and 'Deveci' cultivars were grafted on eight different rootstocks, including two Quince clonal rootstocks (BA29 and QA), five pear clonal rootstocks (FOX9, FOX11, OHxF333, OHxF87, and FAROLD40), and European pear seedling rootstocks were used as plant materials.

Characteristics of Experiment Area

The soil of the study region comprised 2.73 - 10% clay (low), 13.21 - 20% silt (medium), 6.5 - 20% sand (moderate), pH 7.5 (a bit alkaline), 0.2 - 0.3 dS/m salt (no salt), 0.3 - 0.5 organic material (low), 3 - 6% calcium carbonate (low), 0.03 - 0.06 N (low), 5 - 10 ppm P (moderate) level. The depth of the soil is greater than 1 meter. The study area temperature (Max, Average, Min in °C), relative humidity (%), and monthly total precipitation (mm) values are illustrated in Figure 1, Figure 2, and Figure 3.

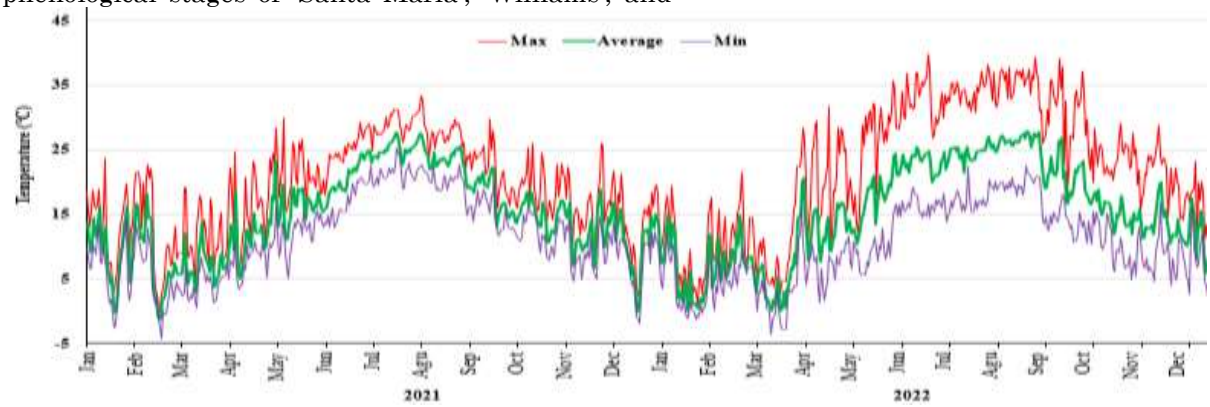

Figure 1. Daily temperature (°C) values of the trial area during the research period
Şekil 1. Araştırma süresince deneme alanındaki günlük sıcaklık (°C) değerleri

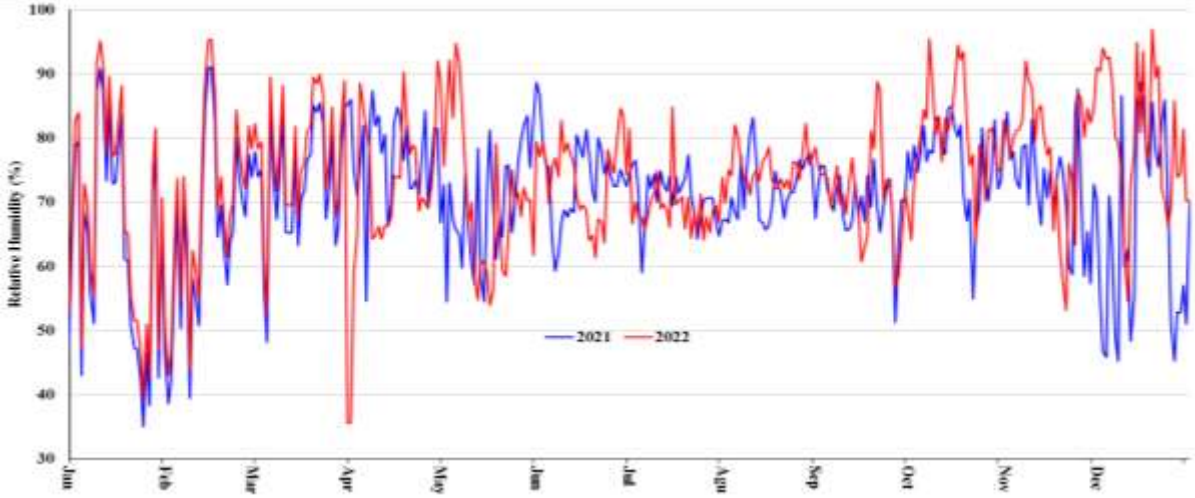

Figure 2. Daily relative humidity (%) values of the trial field during the research period
Şekil 2. Araştırma süresince deneme alanının günlük oransal nem (%) değerleri

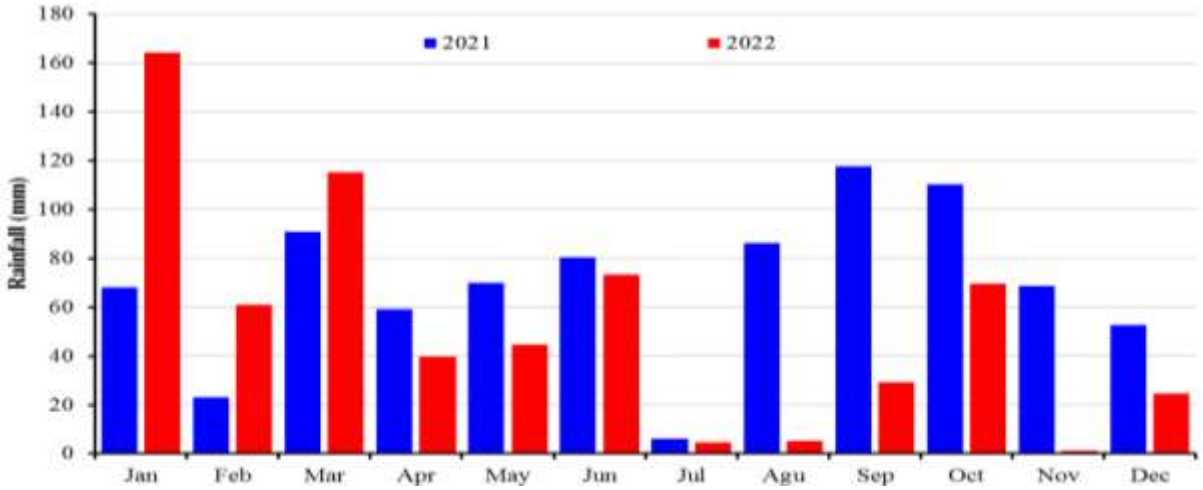

Figure 3. Monthly total precipitation (mm) values of the trial area during the research period
Şekil 3. Araştırma süresince deneme alanına ait aylık toplam yağış (mm) değerleri

Methods

The study was conducted in the pear orchard, which was established in 2018 with 1-year-old saplings at a spacing of 1.5 m by 3.5 m in the case of quince rootstocks and 3.0 m by 3.5 m in the case of pear rootstocks at the Bafra agricultural research center of Ondokuz Mayis University which is located at Samsun province of Turkiye (Figure 4) during two consecutive research years of 2021 and 2022.

Figure 4. Map of the research area
Şekil 4. Araştırma alanının haritası

Phenological Observations

Budburst date (BBD), before flowering date (BFD), balloon stage date (BSD), first flowering date (FirFD), full flowering date (FulFD), end of the flowering date (EFD), fruit se

Budburst date (BBD), before flowering date (BFD), balloon stage date (BSD), first flowering date (FirFD), full flowering date (FulFD), end of the flowering date

(EFD), fruit set date (FSD), harvest maturity date (HMD), and leaf fall date (LFD) (Figure 5) were determined according to previous studies as phenological observations (Oliveira et al., 2017; Kurt et al., 2022). To record the occurance date of each phenological stage, as illustrated in Figure 5, visual inspections of the trees in the orchard were done every day from the first of March until the fruit was set. After then, the visual observations were continued twice a week up to recording the date of leaf fall in different rootstock and cultivar combinations of pear trees (Oliveira et al., 2017). The active growth duration was counted from the bud burst date to the leaf fall, and the dormancy duration was measured from the leaf fall to the bud burst date. The period (in days) from the FirFD to the EFD was calculated as the length of flowering (Mumtaz et al., 2020). t date (FSD), harvest maturity date (HMD), and leaf fall date (LFD) (Figure 5) were determined according to previous studies as phenological observations (Oliveira et al., 2017; Kurt et al., 2022). To record the occurance date of each phenological stage, as illustrated in Figure 5, visual inspections of the trees in the orchard were done every day from the first of March until the fruit was set. After then, the visual observations were continued twice a week up to recording the date of leaf fall in different rootstock and cultivar combinations of pear trees (Oliveira et al., 2017). The active growth duration was counted from the bud burst date to the leaf fall, and the dormancy duration was measured from the leaf fall to the bud burst date. The period (in days) from the FirFD to the EFD was calculated as the length of flowering (Mumtaz et al., 2020).

Statistical Analysis

The research was carried out according to the three-factorial randomized block design, with 3 cultivars, 8 rootstocks, 2 research years, and 3 replications. For each replication 5 plants were used, and the average of those five plants was counted as one replication. The obtained data were analyzed in the IBM SPSS 21.0 statistical package program. The differences between the obtained averages were determined according to the Duncan Multiple Comparison Test at the 5% level ($p<0.05$).

RESULTS

The results of the observations regarding all the phenological stages in 2021 are given in Table 1.

In the research, the bud burst date (BBD) occurred between April 19 and 28.. The BBD occurred the earliest (19 April) in the ‘Deveci’/BA29 combination and the latest (28 April) in the 'Williams’/FOX11 combination. The first flowering date (FirFD) took place between April 26 and May 4. The FirFD occurred the earliest (26 April) in the 'Deveci'/on different rootstocks and the latest (4 May) in the 'Williams'/FOX11 combination. Full flowering date (FulFD) occurred on 29 April–7 May, the earliest (29 April) observed in the combination of ‘Deveci’/QA and the latest (7 May) in the ‘Williams’/FOX11. The flowering date (EFD) ended between May 3 and 15.. The earliest EFD (3 May) was observed in the ‘Deveci’/FOX9, while the latest occurred in the ‘Williams’/FOX11 on 15 May. The fruit set date (FSD) was recorded between May 7 and 23.. The earliest FSD occurred on May 7 in the ‘Deveci’ grafted on BA29 rootstock, and the latest was recorded in the ‘Williams’ grafted on seedling rootstock on May 23. The harvest maturity date (HMD) of the examined cultivars was observed between August 14 and October 28. The earliest (14 August) HMD was obtained in the 'Santa Maria'/QA combination, while the latest (28 October) was in the 'Deveci'/seedling interaction. The leaf fall date (LFD) occurred between November 2 and 20.. It was determined that the earliest LFD was observed on November 2 in the 'Santa Maria'/FOX9 interaction and the latest on November 20 in the 'Deveci'/FAROLD40 interaction (Table 1).

Observations regarding all the phenological phases in 2022 are given in Table 2. The Budburst date (BBD) occurred between April 9 and 12.. The BBD occurred the earliest (9 April) in the 'Deveci' on different rootstocks and 'Santa Maria' on OHxF87 rootstock, the latest (12 April) on 'Williams' and ‘Santa Maria’ on BA29 and QA rootstocks. The first flowering date (FirFD) occurred between April 17 and 23.. The earliest (26 April) FirFD happened in the 'Deveci'on different rootstocks, and the latest (23 April) in the 'Williamson QA and FOX9 rootstocks (Table 2).

Full flowering date (FulFD) was observed on 12-26 April, the earliest (12 April) observed in the ‘Deveci’ on pear clonal and seedling rootstocks, and the latest (26 April) in the ‘Williams’/FOX9 combination. The end of the flowering date (EFD) occurred between April 24 and May 7. The earliest EFD (24 April) was observed in the 'Deveci'/OHxF333, while the latest (7 May) occurred in the 'Williams'/QA combination. The fruit set date (FSD) was recorded between May 7 and 15.. The earliest FSD occurred on May 7 in the ‘Deveci’ grafted on FAROLD4 rootstock, and the latest (15 May) was recorded in the 'Williams' grafted on different rootstocks. The harvest maturity date (HMD) was observed between 10 August and 16 October. The earliest (10 August) HMD was recorded in the ‘Santa Maria’ on QA and OHxF87 rootstocks, while the latest (16 October) was in the 'Deveci'/seedling combination. The leaf fall date (LFD) occurred between November 10 and 29.. The earliest LFD was determined on November 10 in the ‘Santa Maria’/BA29 and the latest on November 29 in the interaction of ‘Deveci’/FOX11 (Table 2).

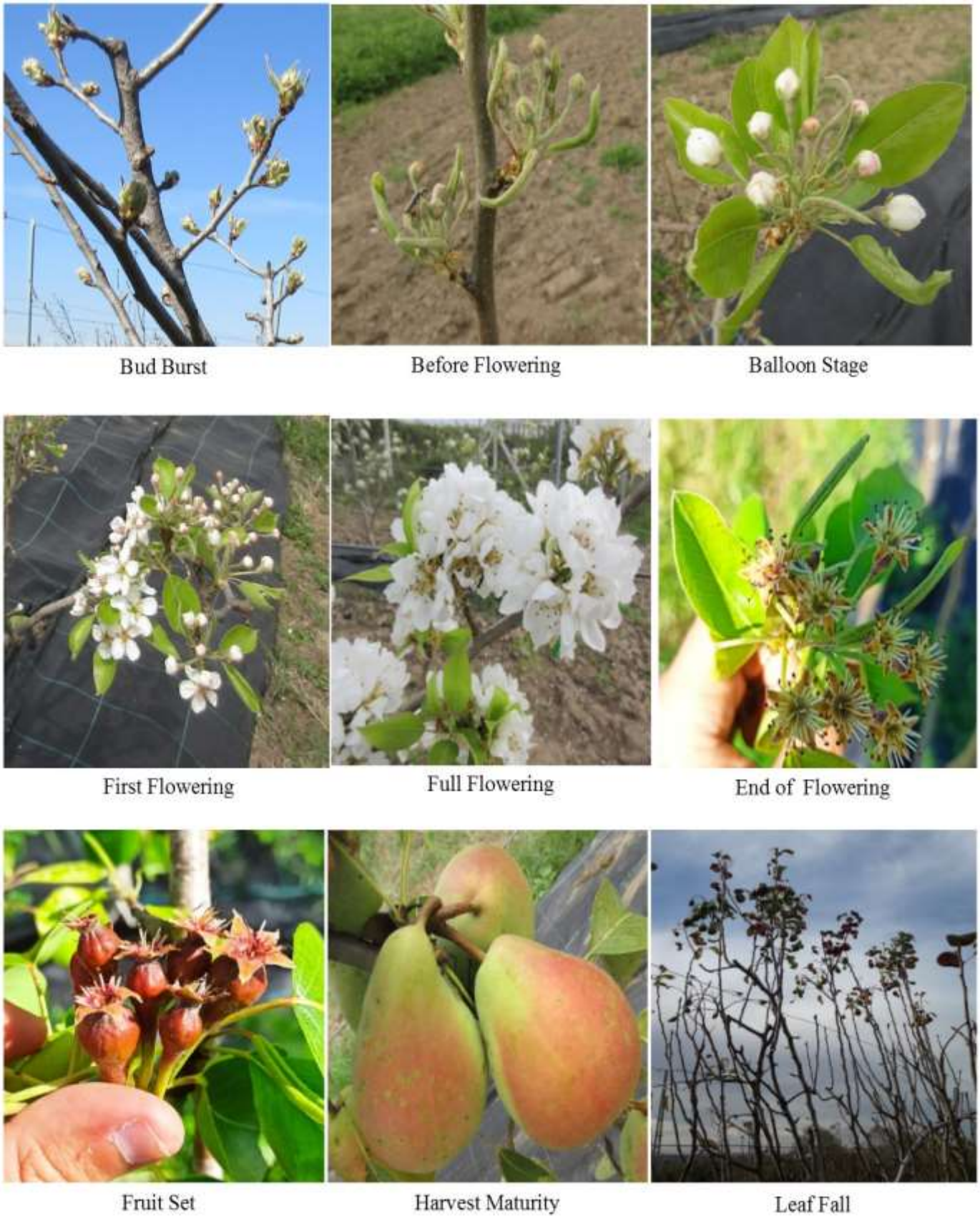

Figure 5. Phenological stages of 'Santa Maria' cultivar grafted on FOX11 pear clonal rootstock
Şekil 5. FOX11 armut klon anacı üzerine aşılı 'Santa Maria' çeşidinin fenolojik safhaları

Table 1. Phenological phases of European pear considering different combinations of rootstocks and cultivars in the year 2021

Çizelge 1. 2021 yılında farklı anaç ve çeşit kombinasyonları dikkate alınarak Avrupa armudunun fenolojik evreleri

Rootstocks	Cultivars	BBD	BFD	BSD	FirFD	FulFD	EFD	FSD	HMD	LFD
BA29	SM	22Apr	27Apr	29Apr	30Apr	3May	7May	10May	17Aug	5Nov
	W	26Apr	28Apr	29Apr	30Apr	3May	7May	10May	09Sep	13Nov
	D	19Apr	21Apr	23Apr	26Apr	3May	5May	7May	21Oct	16Nov
Quince A	SM	21Apr	23Apr	25Apr	26Apr	3May	7May	9May	14Aug	4Nov
	W	26Apr	27Apr	28Apr	29Apr	3May	7May	10May	23Sep	13Nov
	D	20Apr	22Apr	25Apr	26Apr	29Apr	7May	9May	23Oct	17Nov
FOX9	SM	25Apr	26Apr	28Apr	29Apr	4May	9May	17May	17Aug	2Nov
	W	26Apr	28Apr	30Apr	1May	5May	9May	21May	13Sep	11Nov
	D	22Apr	25Apr	27Apr	28Apr	30Apr	3May	14May	21Oct	17Nov
FOX11	SM	22Apr	24Apr	25Apr	27Apr	3May	6May	9May	20Aug	7Nov
	W	28Apr	30Apr	3May	4May	7May	15May	21May	10Sep	14Nov
	D	22Apr	24Apr	26Apr	27Apr	3May	6May	11May	21Oct	18Nov
OHxF333	SM	21Apr	22Apr	24Apr	26Apr	3May	7May	11May	17Aug	5Nov
	W	26Apr	29Apr	30Apr	1May	4May	6May	10May	16Sep	13Nov
	D	21Apr	22Apr	24Apr	26Apr	3May	6May	9May	21Oct	19Nov
OHxF87	SM	22Apr	23Apr	25Apr	26Apr	3May	8May	17May	20Aug	3Nov
	W	25Apr	28Apr	29Apr	2May	5May	12May	19May	13Sep	11Nov
	D	20Apr	22Apr	24Apr	27Apr	1May	4May	16May	21Oct	16Nov
FAROLD40	SM	26Apr	27Apr	29Apr	1May	5May	8May	12May	17Aug	8Nov
	W	27Apr	29Apr	30Apr	1May	4May	9May	18May	8Sep	17Nov
	D	23Apr	26Apr	27Apr	30Apr	3May	6May	10May	23Oct	20Nov
Seedling	SM	26Apr	28Apr	30Apr	3May	6May	11May	17May	20Aug	7Nov
	W	27Apr	30Apr	1May	3May	6May	13May	23May	13Sep	14Nov
	D	25Apr	27Apr	30Apr	1May	4May	9May	19May	28Oct	19Nov

BBD: Bud Burst Date, BFD: Before Flowering Date, BSD: Balloon Stage Date, FirFD: First Flowering Date, FulFD: Full Flowering Date, EFD: End of Flowering Date, FSD: Fruit Set Date, HMD: Harvest Maturity Date, LFD: Leaf Fall Date. SM= 'Santa Maria', W= 'Williams', D= 'Deveci'.

Flowering duration from the FirFD to the EFD of different pear cultivars, including SM ('Santa Maria'), W ('Williams'), and D ('Deveci'), combined with eight different rootstocks, was calculated as the length of flowering and given in Figure 6. Concerning the flowering period, there were noticeable variances between the different combinations. In the research year of 2021, the SM/OHxF87 combination showed a considerably longer flowering duration (12 days). However, flowering time was the shortest (5 days) in the D/FOX9 combination. Significant results were also acquired in the research year 2022; the W/FAROLD40 combination illustrated the longest (17 days) duration of flowering, while the flowering time was the shortest (6 days) in the D/FAROLD40 combination.

The research findings of the main effects of research years, rootstocks, and cultivars, the factor two combination effect, and the factor three combination effect regarding active growth duration (AGD), are illustrated in Table 3. Except for the combined impact of rootstock x cultivars (R x C), which was not significant, all the other main effects and their combination effects were obtained significantly. In the case of the three combination effects of year x rootstocks x cultivars (Y x R x C) on the AGD, the results were obtained in the 187.00–228.34-day range. In the study, the AGD was determined to be the lowest (187.00 days) in the 'Santa Maria'/FOX9 combination in the research year 2021, while the highest (228.34 days) in the 'Deveci'/FOX11 combination in the research year 2022 (Table 3). In the case of the main effect of research year (Y) on the AGD, the obtained results range from 198.38 to 219.46 days. In the study, the AGD was determined to be the lowest (198.38 days) in the research year of 2021 and the highest (219.46 days) in the research year of 2022 (Table 3). Considering the main effect of rootstocks (R) on the AGD, the obtained results varied between 206.33 and 211.33 days. The AGD was found to be the lowest (206.33 days) on the BA29 and FOX9 rootstocks and the highest (211.33 days) on the FOX11 rootstock (Table 3).

Table 2. Phenological phases of European pear considering different combinations of rootstocks and cultivars in the year 2022

Çizelge 2. 2022 yılında farklı anaç ve çeşit kombinasyonları dikkate alınarak Avrupa armudunun fenolojik evreleri

Rootstocks	Cultivars	BBD	BFD	BSD	FirFD	FulFD	EFD	FSD	HMD	LFD
BA29	SM	12Apr	14Apr	17Apr	19Apr	24Apr	29Apr	10May	13Aug	10Nov
	W	12Apr	14Apr	17Apr	19Apr	24Apr	30Apr	11May	31Aug	16Nov
	D	10Apr	13Apr	15Apr	17Apr	21Apr	26Apr	10May	14Oct	19Nov
Quince A	SM	12Apr	14Apr	17Apr	19Apr	22Apr	29Apr	11May	10Aug	17Nov
	W	12Apr	14Apr	19Apr	23Apr	25Apr	7May	15May	28Aug	18Nov
	D	9Apr	11Apr	14Apr	17Apr	22Apr	26Apr	8May	12Oct	23Nov
FOX9	SM	11Apr	16Apr	18Apr	19Apr	24Apr	29Apr	11May	18Aug	19Nov
	W	10Apr	14Apr	19Apr	23Apr	26Apr	6May	15May	27Aug	13Nov
	D	11Apr	13Apr	16Apr	17Apr	19Apr	27Apr	11May	12Oct	21Nov
FOX11	SM	12Apr	14Apr	18Apr	19Apr	23Apr	1May	9May	15Aug	19Nov
	W	11Apr	14Apr	16Apr	18Apr	24Apr	4May	12May	25Aug	27Nov
	D	11Apr	14Apr	17Apr	19Apr	21Apr	29Apr	10May	19Oct	29Nov
OHxF333	SM	11Apr	16Apr	18Apr	19Apr	24Apr	1May	11May	18Aug	12Nov
	W	10Apr	14Apr	17Apr	18Apr	23Apr	4May	12May	31Aug	22Nov
	D	9Apr	13Apr	15Apr	17Apr	19Apr	24Apr	10May	14Oct	26Nov
OHxF87	SM	9Apr	11Apr	18Apr	19Apr	24Apr	26Apr	9May	10Aug	13Nov
	W	11Apr	14Apr	16Apr	19Apr	23Apr	4May	13May	26Aug	28Nov
	D	11Apr	13Apr	16Apr	18Apr	19Apr	27Apr	11May	12Oct	18Nov
FAROLD40	SM	10Apr	14Apr	16Apr	18Apr	22Apr	28Apr	9May	19Aug	18Nov
	W	10Apr	16Apr	17Apr	19Apr	24Apr	6May	13May	01Sep	20Nov
	D	11Apr	16Apr	17Apr	19Apr	21Apr	25Apr	7May	14Oct	22Nov
Seedling	SM	11Apr	14Apr	16Apr	18Apr	21Apr	29Apr	11May	13Aug	22Nov
	W	10Apr	13Apr	18Apr	20Apr	23Apr	6May	15May	04Sep	25Nov
	D	9Apr	12Apr	16Apr	17Apr	19Apr	26Apr	12May	16Oct	25Nov

BBD: Bud Burst Date, BFD: Before Flowering Date, BSD: Balloon Stage Date, FirFD: First Flowering Date, FulFD: Full Flowering Date, EFD: End of Flowering Date, FSD: Fruit Set Date, HMD: Harvest Maturity Date, LFD: Leaf Fall Date. SM= 'Santa Maria', W= 'Williams', D= 'Deveci'.

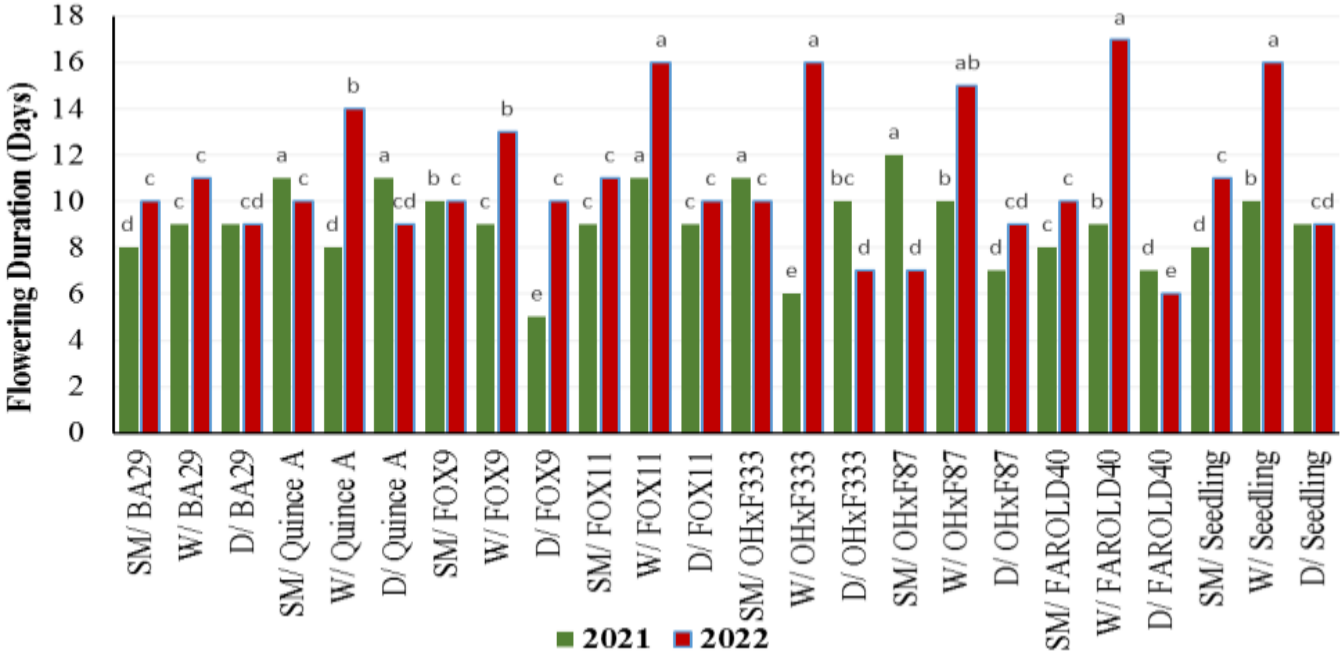

Figure 6. Flowering duration of different pear SM ('Santa Maria'), W ('Williams'), and D ('Deveci') pear cultivars combined with different rootstocks

Şekil 6. Farklı anaçlarla kombine edilen farklı armut çeşitlerinin SM ('Santa Maria'), W ('Williams') ve D ('Deveci') çiçeklenme süresi

Table 3. Active growth duration of European pear considering different rootstocks, cultivars, research years, and their combination

Çizelge 3. Farklı anaçlar, çeşitler, araştırma yılları ve bunların kombinasyonları dikkate alınarak Avrupa armudunun aktif büyüme süresi

Rootstocks (R)	Cultivars (C)	Year		Total
		2021	2022	
		Mean	Mean	Mean
BA29	Santa Maria	193.1±2.30 pqr	208.0±2.32 j-m ♠	200.6±3.65 A † Φ
	Williams	197.7±2.31 opq	214.1±2.33 g-k	205.5±4.07 A
	Deveci	207.2±2.30 k-n	219.0±2.29 c-h	213.0±3.05 A
Quince A	Santa Maria	193.0±2.32 pqr	215.4±2.28 f-j	204.1±5.13 A
	Williams	197.3±2.29 opq	216.0±2.31 f-i	206.5±4.49 A
	Deveci	207.0±2.30 k-n	224.7±2.30 a-e	215.4±4.07 A
FOX9	Santa Maria	187.0±2.31 r	218.4±2.31 d-i	202.5±7.08 A
	Williams	195.2±2.32 pq	213.8±2.30 h-l	204.1±4.28 A
	Deveci	205.1±2.32 mn	220.6±2.30 b-h	212.5±3.65 A
FOX11	Santa Maria	195.0±2.30 pq	217.2±2.29 e-i	206.0±5.13 A
	Williams	196.0±2.29 pq	226.4±2.32 abc	211.3±6.86 A
	Deveci	206.0±2.32 lmn	228.4±2.33 a	217.0±5.13 A
OHxF333	Santa Maria	194.5±2.31 pqr	211.0±2.30 i-m	202.5±4.07 A
	Williams	197.7±2.32 opq	222.4±2.30 a-f	209.5±5.77 A
	Deveci	208.1±2.30 j-m	227.0±2.31 ab	217.5±4.49 A
OHxF87	Santa Maria	191.0±2.29 qr	214.5±2.32 g-k	202.4±5.34 A
	Williams	196.0±2.32 pq	227.0±2.30 ab	211.6±7.08 A
	Deveci	206.6±2.33 lmn	217.3±2.32 e-i	211.5±2.86 A
FAROLD40	Santa Maria	192.0±2.31 qr	218.0±2.33 d-i	205.3±5.99 A
	Williams	200.0±2.30 nop	220.0±2.30 b-h	210.0±4.70 A
	Deveci	207.4±2.30 l-n	221.5±2.29 a-g	214.2±3.45 A
Seedling	Santa Maria	191.0±2.31 qr	221.2±2.29 a-g	206.0±6.86 A
	Williams	197.3±2.32 opq	225.4±2.30 a-d	211.0±6.42 A
	Deveci	204.0±2.31 mno	226.0±2.32 abc	215.3±5.13 A
Pooled Standard Error (±)			2.309	1.041
Significance			0.022	0.283
			Y	
Years (Y)		198.4±0.82 B	219.5±0.74 A †† Φ	
Pooled Standard Error (±)			1.041	
Significance			0.001	
		2021	2022	Total Mean
Rootstocks	BA29	199.0±2.38 c	213.6±1.96 b ♠	206.3±2.32 B † Φ
	Quince A	199.0±2.38 c	218.3±1.83 ab	208.7±2.66 AB
	FOX9	195.7±2.84 c	217.0±1.55 ab	206.3±3.02 B
	FOX11	199.0±2.10 c	223.6±2.04 ab	211.3±3.36 A
	OHxF333	199.7±2.42 c	220.0±2.62 ab	209.8±3.01 A
	OHxF87	197.7±2.88 c	219.3±2.27 ab	208.5±3.09 AB
	FAROLD40	199.6±2.45 c	219.7±1.23 ab	209.7±2.76 A
	Seedling	197.3±2.20 c	224.0±1.38 a	210.6±3.47 A
Pooled Standard Error (±)			1.333	1.041
Significance			0.002	0.001
		2021	2022	Total Mean
Cultivars	Santa Maria	192.0±0.83 e	215.2±1.06 b ♠	203.6±1.82 C † Φ
	Williams	196.8±0.73 d	220.4±1.27 a	208.7±1.86 B
	Deveci	206.2±0.72 c	222.7±1.04 a	214.5±1.35 A
Pooled Standard Error (±)			0.816	1.041
Significance			0.001	0.001

†:Means with different letters in the same column are significant. ††: Means with different letters in the same row are significant. Φ: Rootstock x Cultivar combined effect, year main effect, rootstock main effect and cultivar main effect are specified with capital letters. ♠:The RootstockxCultivarxYear combined effect, Rootstocks x Year combined effect, and Cultivar x Year combined effect are specified with small letters. N=144 (8 rootstocks * 3 cultivars * 2 years* 3 replications = 144).

The main effects of research years, rootstocks and cultivars, the factor two combination effects, and the factor three combination effects on the dormancy duration (DD) are given in Table 4.

Table 4. Dormancy duration of European pear considering different rootstocks, cultivars, research years, and their combination

Çizelge 4. Farklı anaçlar, çeşitler, araştırma yılları ve bunların kombinasyonları dikkate alındığında Avrupa armudunun dinlenme süresi

Rootstocks (R)	Cultivars (C)	Year		Total
		2021	2022	
		Mean	Mean	Mean
BA29	Santa Maria	167.0±2.30 a	152.4±2.29 a ♠	159.7±3.65 A † Φ
	Williams	163.0±2.30 a	146.0±2.30 a	154.5±4.07 A
	Deveci	153.0±2.30 a	141.0±2.29 a	147.0±3.05 A
Quince A	Santa Maria	167.0±2.31 a	145.0±2.29 a	156.0±5.13 A
	Williams	163.4±2.30 a	144.7±2.30 a	154.1±4.46 A
	Deveci	153.0±2.32 a	136.0±2.30 a	144.5±4.07 A
FOX9	Santa Maria	173.6±2.31 a	142.0±2.30 a	157.8±7.08 A
	Williams	165.0±2.30 a	147.0±2.31 a	156.0±4.28 A
	Deveci	155.0±2.29 a	140.0±2.29 a	147.5±3.65 A
FOX11	Santa Maria	165.3±2.30 a	143.0±2.30 a	154.1±5.13 A
	Williams	164.0±2.29 a	134.0±2.29 a	149.0±6.86 A
	Deveci	154.0±2.29 a	132.0±2.30 a	143.0±5.13 A
OHxF333	Santa Maria	166.0±2.30 a	149.0±2.31 a	157.5±4.07 A
	Williams	163.0±2.30 a	138.0±2.30 a	150.5±5.77 A
	Deveci	152.0±2.31 a	133.0±2.31 a	142.5±4.49 A
OHxF87	Santa Maria	169.0±2.30 a	146.0±2.30 a	157.5±5.34 A
	Williams	164.0±2.29 a	133.0±2.29 a	148.5±7.08 A
	Deveci	154.0±2.31 a	143.0±2.31 a	148.5±2.86 A
FAROLD40	Santa Maria	168.0±2.32 a	142.0±2.31 a	155.0±5.99 A
	Williams	160.0±2.30 a	140.0±2.29 a	150.0±4.70 A
	Deveci	153.0±2.30 a	139.0±2.30 a	146.0±3.45 A
Seedling	Santa Maria	169.0±2.31 a	139.0±2.30 a	154.0±6.86 A
	Williams	163.0±2.32 a	135.0±2.29 a	149.0±6.42 A
	Deveci	156.0±2.29 a	134.0±2.31 a	145.0±5.13 A
Pooled Standard Error (±)			2.887	2.041
Significance			0.219	0.695
			Y	
Years (Y)		161.6±0.82 A	140.5±0.74 B †† Φ	
Pooled Standard Error (±)			0.589	
Significance			0.001	
		2021	2022	Total Mean
Rootstocks	BA29	161.0±2.38 a	146.3±1.96 b ♠	153.7±2.32 A † Φ
	Quince A	161.1±2.38 a	141.7±1.83 bc	151.3±2.72 AB
	FOX9	164.3±2.84 a	143.0±1.55 bc	153.7±3.06 A
	FOX11	161.0±2.10 a	136.3±2.04 c	148.7±3.31 B
	OHxF333	160.3±2.42 a	140.0±2.62 bc	150.2±3.01 AB
	OHxF87	162.1±2.48 a	140.7±2.57 bc	151.5±3.09 AB
	FAROLD40	160.3±2.45 a	140.3±1.23 bc	150.3±2.76 AB
	Seedling	162.7±2.20 a	136.0±1.38 c	149.3±3.47 B
Pooled Standard Error (±)			1.667	1.041
Significance			0.031	0.023
		2021	2022	Total Mean
Cultivars	Santa Maria	168.0±0.83 a	144.7±1.06 d ♠	156.4±1.82 A † Φ
	Williams	163.1±0.73 b	139.6±1.27 e	151.3±1.86 B
	Deveci	153.8±0.72 c	137.3±1.44 e	145.5±1.35 C
Pooled Standard Error (±)			1.041	0.722
Significance			0.001	0.001

†: Means with different letters in the same column are significant. ††: Means with different letters in the same row are significant. Φ: Rootstock x Cultivar combined effect, year main effect, rootstock main effect and cultivar main effect are specified with capital letters. ♠: The Rootstock x Cultivar x Year combined effect, Rootstocks x Year combined effect, and Cultivar x Year combined effect are specified with small letters. N=144 (8 rootstocks * 3 cultivars * 2 years* 3 replications = 144).

Except for the combined impact of research year x rootstock x cultivars (Y x R x C) and rootstock x cultivars (R x C), which were recorded as insignificant, all the other main effects and their combination effects were acquired as significant. Regarding the main impact of research year (Y) on the DD, the obtained results range from 140.54 - 161.63 days. In the study, the DD was determined as the lowest (140.54 days) in the research year of 2022 and the highest (161.63 days) in the research year of 2021 (Table 4). Considering the main effect of rootstocks (R) on the DD, the obtained results varied between 148.67 - 153.67 days. The DD was found to be the lowest (148.67 days) on the FOX11 rootstock, while the highest (153.67 days) on the BA29 and FOX9 rootstocks (Table 4). The main effect of cultivars (C) on the DD is ranging 145.50 - 156.38 days. The DD was acquired the lowest (145.50 days) in the 'Deveci' while the highest (156.38 days) in the 'Santa Maria' cultivar (Table 4).

DISCUSSIONS

The phenological observations obtained during the investigation revealed notable variations based on the years (Pio et al., 2023) and certain differences based on rootstocks and cultivars (Kurt et al., 2022). The difference between the years was due to the climatic differences in the research years (Kurt et al., 2022; Pio et al., 2023). The research determined that the temperature values in April and after that, when the buds burst and the active vegetative growth began, were higher in 2022 compared to 2021 (Figure 1). Due to that, the phenological stages started earlier in 2022; on the contrary, the active growth period ended earlier in 2021 (20 November) than the research year of 2022 (29 November). From the 24 combinations in 2021, it was observed that the 'Deveci' cultivar grafted on BA29 showed earlier phenological stages compared to other combinations. In 2022, the same cultivar, namely 'Deveci', illustrated earlier phenological phases on different rootstocks. No obvious differences were observed between rootstocks regarding harvest maturity date, especially in 2021, but the rootstocks showed distinct variation with the similar cultivar combination. The differences between cultivars were noticeable, considering the harvest maturity date (around 70 days between 'Santa Maria' and 'Deveci'). It was observed that the cultivar with the earliest fruit harvest was 'Santa Maria' and the latest was 'Deveci'. The different genetic make-up of the trees brings on this circumstance.

It was noted in earlier studies on related topics that the phenological variations between cultivars were mainly caused by genetic variations as well as the climate in which trees are grown (Dondini and Sansavini, 2012; Osmanoğlu et al., 2013; Öztürk et al., 2016; Ozturk et al., 2022). In hot and dry weather, all the flowers on the tree open quickly; in cool and rainy weather, flowering continues on the same tree for 2–10 days (Kurt et al., 2022). On the contrary, Pio et al. (2023) stated that under subtropical climate situations, pear trees without the use of irrigation had a very long flowering duration as compared to the irrigated trees. This can cause an extension of the harvest duration as well. Our research observed that the temperature (Figure 1) and humidity (Figure 2) values at the end of April and May, when flowering occurs, were higher in 2022 than in the research year of 2021. The flowering season was shortened in 2022 due to the higher temperature and relative humidity. It has been noted that the phenological indicators we observed in the research are consistent with the findings of earlier investigations. Considering the 24 treatment combinations of the present research, it took 9–10 days for the buds to pass from dormancy (bud burst) to the full bloom stage in 2021 and 8–11 days in 2022. While considering the cultivars, it took approximately 11 days for 'Santa Maria', 14 days for 'Williams', and 8 days for the 'Deveci' cultivar. This means that the 'Deveci' cultivar's flowering habit is more synchronized than other cultivars that were used in the study. Similar results were reported by Pio et al. (2023), who stated that some cultivars flowering habits are more synchronized while they compared various cultivars's flowering periods. The prolonged period from bud burst to full flowering can decrease fruiting, probably because of competition for nutrient elements between the vegetative growth and flowering buds. So, this period should be taken strictly into consideration to avoid a breakdown in the normal fruiting of the trees (Oliveira et al., 2017). Considering the phenological stages of nine pear cultivars ('William Bartlett', 'Fertility', 'Chinese Sandy Pear', 'Clapp's Favourite', 'Max Red Bartlett', 'Kings Pear', 'Beurre de Amanalis,' 'Carmen' and 'Abate Fetel') in the temperate climatic condition of India, all the cultivars were reported to perform significant differences in their phenological stages and flowering performance. The flowering pattern of cultivars revealed that 'Chinese Sandy Pear' and 'Kings Pear' were the first to come into flower, followed by 'Clapp's Favorite' and 'Beurre de Amanalis', whereas 'William Bartlett', 'Max Red Bartlett', 'Fertility', 'Carmen', and 'Abate Fetel' were observed to be late bloomers. The flowering duration reported was longest (15 days) in 'Fertility' followed by 14.67 and 14.22 days in 'William Bartlett' (14.67 days), 'Max Red Bartlett' (14.22 days), and the shortest (11.45 days) in 'Chinese Sandy Pear' (Mumtaz et al., 2020). Similarly, our study observed differences in the flowering behavior between the various rootstock and cultivar combinations that were used in the study. In pear trees, understanding the

flowering time is an important criterion due to the need to synchronize flowering with pollinating cultivars (Pio et al., 2023), as most pear cultivars have gametophytic self-incompatibility, causing the trees to reject their own pollen (Bisi et al., 2019; 2021). Therefore, they depend on cross-pollination, and the use of two to three pear cultivars with a coincident flowering period is strictly recommended for pear orchards (Tatari et al., 2017). Phenological stages of pear trees, including flowering, are influenced by many internal and external factors, like light intensity, hormone concentration, plant age (Cong et al., 2023), cultivars (Kumar et al., 2023), rootstocks (Kurt et al., 2022), and temperature (Fadon et al., 2023), especially temperature in the previous growing season as well as during the dormancy period of trees (Martinez-Nicolas et al., 2016; Fernandez et al., 2021). Similarly, in our study, the phenological stages and dormancy period were significantly affected by different pear cultivars, rootstocks, and climatic situations in the two consequent research years.

CONCLUSION

Due to the short duration of productive growth stages ranging from flower formation to fruit harvest, the 'Santa Maria' pear cultivar in combination with all rootstocks was found to be the best for Samsun ecological conditions (temperate humid). Also, the 'Williams' cultivar in combination with all rootstocks observed ideal in the second position. However, the 'Deveci' cultivar, in combination with all rootstocks, needs very long productive growth from flower formation to fruit harvest, which is negatively affected by biotic and abiotic stresses. While the 'Deveci' cultivar in combination with the FOX9 and OHxF87 rootstocks observed better combinations than others due to the shorter productive growth period, Briefly, the AGD and DD of fruit trees should be understood to manage fruit orchards effectively and scientifically. Finally, combining cultivars with rootstocks that exhibit lower AGD in temperate, humid climates is suggested since this will be more effective at reducing the negative impacts of stress factors.

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Conflict of Interest

Regarding this work's research, writing, and/or publication, the authors affirm that there are no interest concerns.

Contribution of Authorship

ZAF: Gathered the information, analysed the data, and wrote the manuscript. AÖ: conceptualized and designed the study and checked and corrected the final draft.

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