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HORTICULTURAL STUDIES

RESEARCH PAPER

Assessing Autumn Cold Hardiness in Newly Planted Fruit Trees and Grapevines

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Abstract

Low-temperature damage is one of the key factors that limits the distribution of tree species in an area. This damage is not always the result of low temperatures in winter or during bloom. Actively growing trees or parts of trees do not harden, may be injured by lower temperatures or erratic temperature fluctuations in autumn. It is essential that the capability of each separate scion/rootstock combination to tolerate cold temperatures should be tested especially when the trees are young and a serious climate change is taking place. The overall goal of this study was to investigate the effect of early autumn temperature on fruit and grapevine species, including various cultivars and rootstocks, after plantings and to determine the cold hardiness. The autumn term of 2022 was one of the periods we have experienced notable temperature fluctuations was observed, particularly in September. The day-night temperature difference reached 21.5°C on September 24. Subsequent field observations revealed significant variation in autumn cold tolerance among species, cultivars, and rootstocks. In this study, cold injury was observed in fifteen of the 29 examined species in the autumn after planting. During unfavourable autumn conditions, young trees of fig, persimmon, walnut, and chestnut cultivars were classified as very susceptible. It is most likely that the hardening process in these four species was more affected by erratic temperature fluctuations in the early phase of hardening.

1. Introduction

Spring frosts represent a significant hindrance to the successful cultivation of fruit and grapevine species in most regions, frequently resulting in substantial economic losses (Ashworth and Wisniewski, 1991; Tromp, 2005). Therefore, considerable attention has been devoted to studying the prevention of freezing injury during bloom, particularly in various *Prunus* cultivars (Chmielewski et al., 2018; Dumanoglu et al., 2019; Demirsoy et al., 2022).

After grapevines have commenced growth, temperatures below 10°C can halt development, contingent upon the severity and duration of the cold spell; if temperatures near freezing (0°C) endure, developing shoots may suffer damage; in cold regions, early autumn frosts pose a risk, potentially harming grapevine shoots not yet fully matured (Çelik et al., 1998; Ren et al., 2023). Low-temperature damage in autumn or winter is relatively uncommon in temperate zones. However, in recent years, injuries caused by autumn or winter frost have been gradually increasing in extensive commercial production areas in Türkiye, especially in new plantings.

Various injuries caused by lower temperatures in grapevines and fruit species may occur in the autumn or winter, including browning of xylem cells (blackheart), cambium injury, crotch injury, crown/collar injury, splitting of trunks, winter sunscald or bark splitting on the trunk or main branches, shoot death/dieback, killing of dormant flower buds, and rarely, root injury (Pearce, 2001; Tromp, 2005). The degree of injury depends on plant species/cultivar, stage of development, temperature, rate of temperature change, and the ability to tolerate low temperatures (Westwood, 1993; Rodrigo, 2000; Yu and Lee, 2020).

Soil conditions, management factors, the age of the plant, and the hardening phase can all influence the ability to tolerate freezing stress (Rochette et al., 2004). Some fully hardened woody plants are extremely tolerant to freezing stress in winter, reaching temperatures as low as -45°C and -35°C for fruit trees such as apple, pear, and peach (Tromp, 2005). In contrast, some young and nursery plants do not fully harden in autumn or early winter, as growth may continue during autumn, and they may be injured by lower temperatures or erratic temperature fluctuations (Walke, 2014; Wisniewski et al., 2018; Repo et al., 2021).

It has been predicted that climate change will alter the conditions affecting the phenology, frost hardiness of plants, and cold acclimation. However, the knowledge of how different fruit and grapevine species respond to changes in photoperiod and temperature in late summer and autumn is limited. To address this gap, it was conducted observations on autumn frost hardiness in fruits and grapevines, encompassing various cultivars and rootstocks, following plantings in the conditions of the Lake Region (Türkiye), renowned for its significant fruit production capacity.

2. Materials and Methods

The experiment was conducted at Burdur Mehmet Akif Ersoy University, Burdur, Türkiye (37°41′15″ N, 30°20′38″ E). The mean annual rainfall is 426.4 mm, mostly falling in autumn and winter (September to April), and the mean annual air temperature is 13.3°C. The average winter (December to February) and summer (June to August) temperatures are 3.5°C and 23.4°C, respectively.

Twenty-nine species/crosses from twenty genera were selected, considering their potential in the region. The rootstocks and rootstock-cultivar combinations used in the study are detailed in Table 1. Each genotype was represented by three plants, with one plant per plot in three replications. After lifting from the nursery, the plants were transplanted in January 2021.

Row and inter-row distances were designed according to commercial standards and the development characteristics of the genotypes. Management practices, including irrigation, nutrition, pest and disease control, as well as weed management, were conducted in accordance with local commercial orchards from 2021 to 2023.

Meteorological data were collected from a nearby meteorological station. The autumn frost hardiness of the plants was assessed in the field at the beginning of December 2022 through visual evaluation. Damages to plant tissues and organs were evaluated on a scale from 0 to 5, where 0 indicates no visible injury, and 5 indicates plants destroyed entirely by cold (Krasova et al., 2020). All figures were created using the ggplot2 package in R version 4.1.3 (R Core Team, 2022).

3. Results and Discussion

The autumn term of 2022 marked one of the periods with the highest temperature fluctuations in recent years, raising questions about the cold hardiness of our fruit and grapevine species. Daily air temperatures (minimum and maximum) and the difference in day-night temperatures were recorded at the study site from September 2022 to November 2022. Notably, the temperature difference between day and night exceeded 15°C on a total of 11 days in September, 7 days in October, and 6 days in November (Figure 1).

Significant temperature fluctuations, particularly in September, were observed. Through continuous field observations, we determined that autumn frost occurred on September 24, coinciding with the day when the temperature difference between day and night reached 21.5°C. It's noteworthy that the pictures in Figure 2 were taken on September 25.

Fruit trees and grapevines undergo gradual hardening as they are exposed to decreasing temperatures during the transition from late summer to fall and early winter, influenced by the shortening day length (Walke, 2014). Most fruit and grapevine species currently cultivated in the Lake Region are well adapted to these fall hardening conditions. Nevertheless, climate change, warm spells, and fluctuations from cold to warmer temperatures can disrupt this hardening process, thereby increasing the risk of frost injury (Rochette et al., 2004; Lenz et al., 2013; Vitasse et al., 2014). In this study, we observed this full range of situations in September 2022. The discoloration of freeze-injured tissues was visibly apparent at the end of September. The level of cold hardiness in plants can vary depending on when low temperatures occur, how quickly the temperature changes, and how long the low temperatures persist (Rodrigo, 2000; Pearce, 2001). A loss of hardiness due to erratic temperature fluctuations could increase plant vulnerability to freeze damage (Rochette et al., 2004; Wisniewski et al., 2018).

The fruit and grapevine species exhibited varying degrees of resistance to adverse autumn conditions in the Lake Region, as illustrated in Figure 3. Fig (Melli Yemişi), persimmon (Rojo Brillante), and walnut cultivars (Chandler, Iverto,

Table 1. List of the investigated fruit and grapevine species.

Genus	Species/Cross	Rootstock-Cultivar Combinations*	Rootstocks/Own-Rooted Cultivars
Castanea	Chestnut	Kemer/Seedling	-
Corylus	Hazelnut	-	Yomra*, Yağlı*
Crataegus	Hawtorn	Sarı Alıç/Seedling, Kırmızı Alıç/Seedling	-
Cydonia	Quince	Eşme/Quince A	Quince BA29*[R], Quince A*[R]
Diospyrus	Persimmon	Rojo Brillante/Seedling	-
Ficus	Fig	-	Melli Yemişi*
Fragaria	Strawberry	-	Albion*, Rubygem*
Juglans	Walnut	Chandler/Seedling Iverto/Seedling, Pedro/Seedling	-
Lycium	Gojiberry	-	Orange*
Malus	Apple	Anna/MM111, Scarlet Spur/MM111	M9*[R], MM106*[R], MM111*[R] Fuji (Seedling)[R]
Mespilus	Medlar	İstanbul/Quince A	-
Morus	Mulberry	-	Beyaz Dut*
Olea	Olive	Gemlik/Delice (Seedling)	Delice (Seedling)[R]
Pistacia	Pistachio	-	Siirt (Seedling)[R], Buttum (Seedling)[R]
Prunus	Almond	Makako/GF677	-
	Almond × Peach	-	Garnem*[R], GF677*[R]
	Mahalep × Mazzard	-	Maxma 14*[R]
	Peach	Elegant Lady/GF677 Samantha/GF677, Monreo/GF677	-
	Plum	Stanley/Myrobolan 29C	Rootpac 20*[R], Marianna 2624*[R] Pixy*[R], Myrobolan 29C*[R]
	Plum × Almond	-	Rootpac R*[R]
	Plum × Apricot	-	Kayısı Eriği*[R]
	Sweet Cherry	Premier Giant/Maxma 14 0900 Ziraat/Maxma 14 Regina/Maxma 14, Staccato/Maxma 14	-
	Sour Cherry	Kütahya/Maxma 14	-
Pyrus	Pear	Triumph de Vienna/Quince BA29	-
Rubus	Raspberry	-	Willamette*
	Blackberry	-	Jumbo*
Vaccinium	Cranberry	-	Yalçınkaya77*
Vitis	Grapevine	-	41B*[R], 8B*[R], 110R*[R], 99R*[R] 1103P*[R], 140Ru*[R], 5BB*[R]
Ziziphus	Jujube	-	Gazipaşa*, Denizli*

*: Vegetatively propagated, [R]: Rootstock.

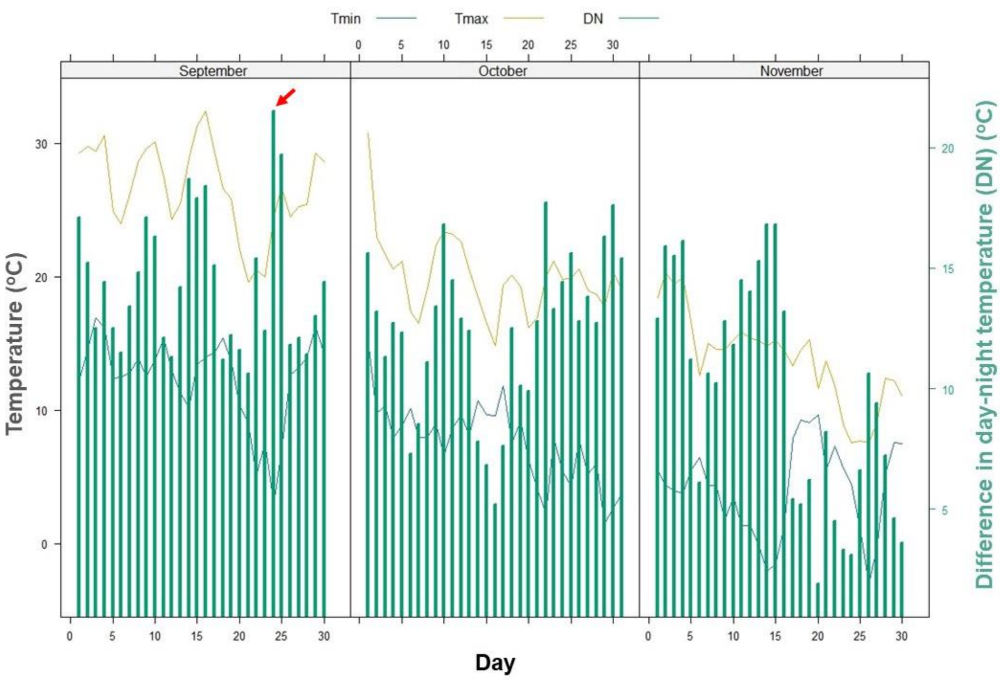

Figure 1. Air temperatures recorded at the research site during the autumn months of 2022 ('Tmin' represents the minimum temperature, while 'Tmax' represents the maximum temperature. The red arrow highlights the difference in day-night temperature “DN” observed on September 24, 2022).

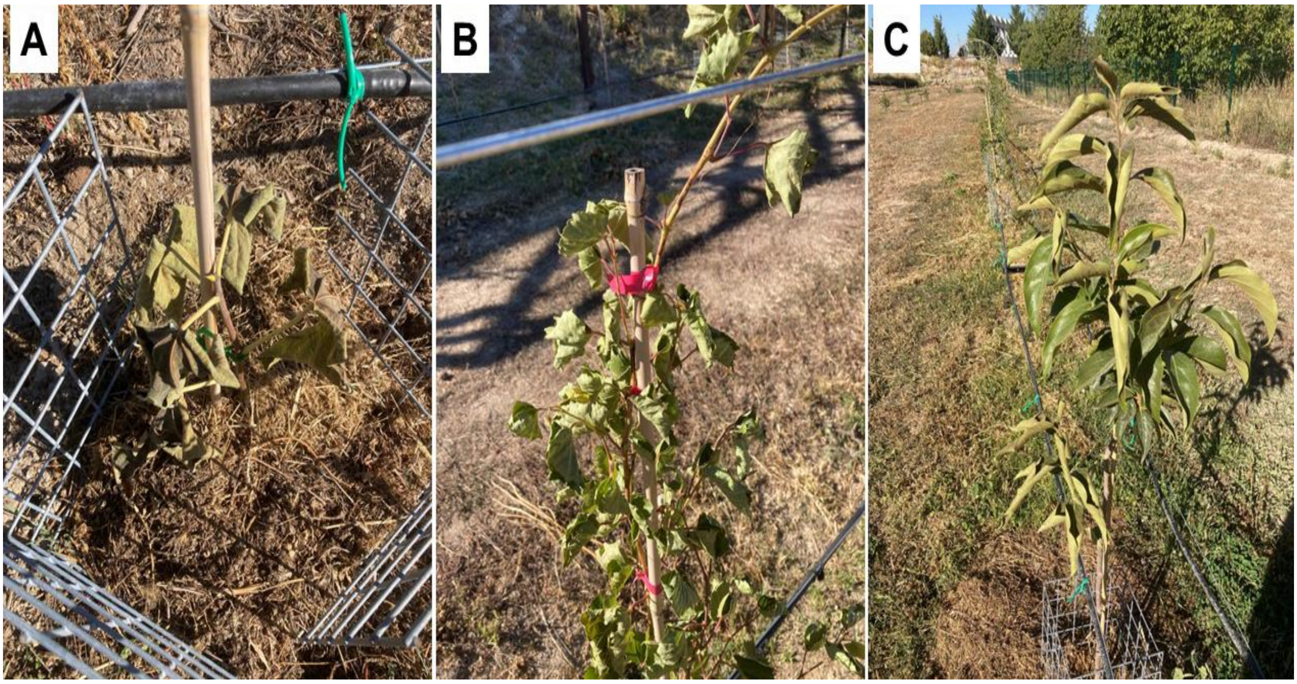

Figure 2. Views of damaged plants taken on September 25 following the frost event on September 24 (A: Melli Yemişi, B: Grapevine “140Ru”, and C: Persimmon “Rojo Brillante/Seedling”).

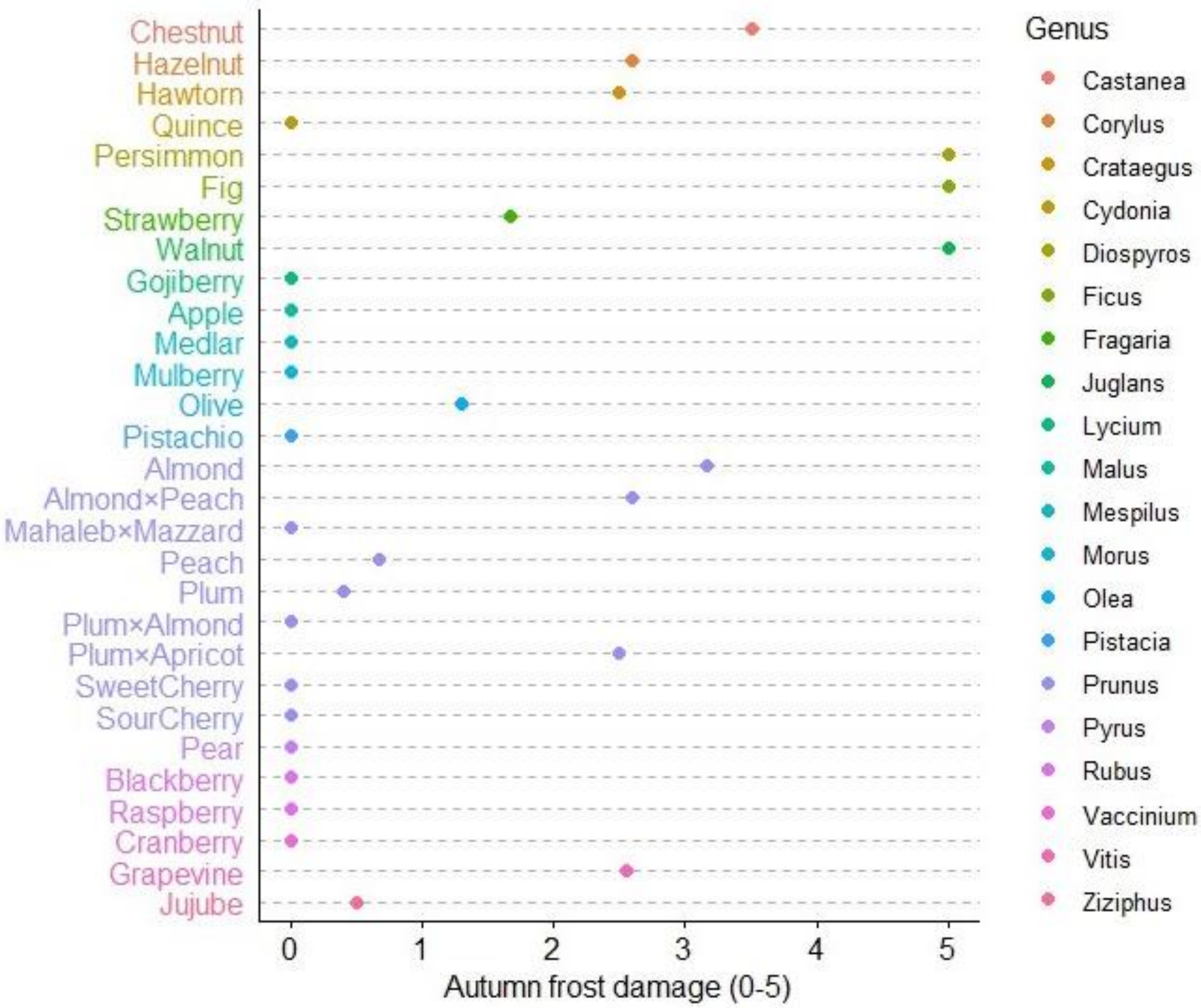

Figure 3. Damage degree of fruit and grapevine species and crosses after the autumn frost (The rating scale ranges from 0: no visible injury to 5: shoot system of plants damaged entirely by autumn cold).

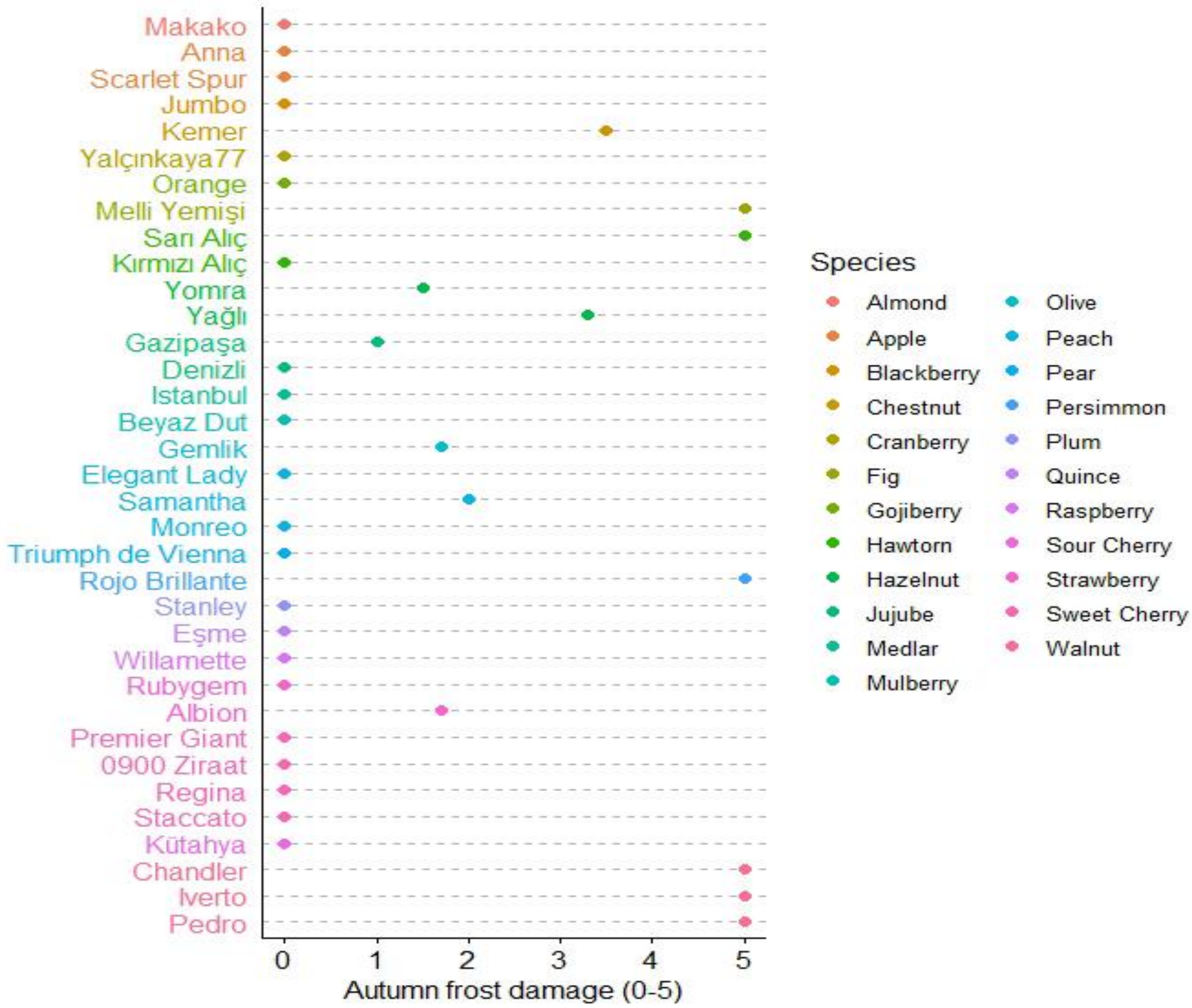

Figure 4. Damage degree of fruit and grapevine cultivars in field conditions after the autumn frost (The rating scale ranges from 0: no visible injury to 5: shoot system of plants damaged entirely by autumn cold).

Pedro) were classified as the most cold-susceptible, with average ratings of 5.0 points, resulting in almost all of their trees entirely dying. The above ground parts of fig, persimmon, and walnut varieties are completely dead. However, the following year, new shoots emerged from underground. Since the fig was propagated by cuttings, the genotype obtained the following year remained the same. On the other hand, in persimmon and walnut cultivars propagated by grafting, the plants obtained the following year were from seedling rootstocks. Chestnut and almond trees experienced cold damage, with freezing injury indexes recorded at 3.5 and 3.2, respectively. Almond cultivar Makako trees largely recovered within a year, producing new shoots. In contrast, trees of the chestnut cultivar 'Kemer' entirely died. The mean autumn frost damage values of the species hazelnut, grapevine, hawthorn, and the crosses Almond × Peach and Plum×Apricot were approximately 2.5 points, indicating intermediate hardiness (Figure 3).

There was significant variation in the autumn cold tolerance of the same species when comparing among cultivars and rootstocks for each of these species. Hazelnut cultivars showed injuries of 3.3 and 1.5 points for Yağlı and Yomra, respectively. Interestingly, Sarı Alıç was classified as the most autumn susceptible (5.0 points), and almost all of its trees were totally damaged, while there was no damage in Kırmızı Alıç. Among strawberry, peach, and jujube cultivars, only Albion (1.7), Samantha (2.0), and Gazipaşa (1.0) were partially damaged (Figure 4).

Damages of almond-peach hybrid rootstocks were scored as 1.5 and 3.3 for GF677 and Garnem, respectively. Grapevine rootstocks showed large variation in cold hardiness. The rootstocks 5BB (5 points), 140Ru (4.5 points), and 99R (4.3 points) were seriously injured, whereas it was observed that only minimal injury occurred in the rootstocks 1103P (1 point), 110R (1 point), 8B (0.6 points), and 41B (0.6 points). The rootstock Myrobolan 29C was the only plum rootstock that was damaged with an index value of 2.0. In olive, the freezing injury index of the Delice rootstock was 1 point, while this value was determined as 1.7 in the Gemlik cultivar grafted onto the same rootstock (Figure 5).

In our experiment, it was observed that there was no visible injury to trees of medlar, quince, cranberry, gojiberry, raspberry, blackberry,

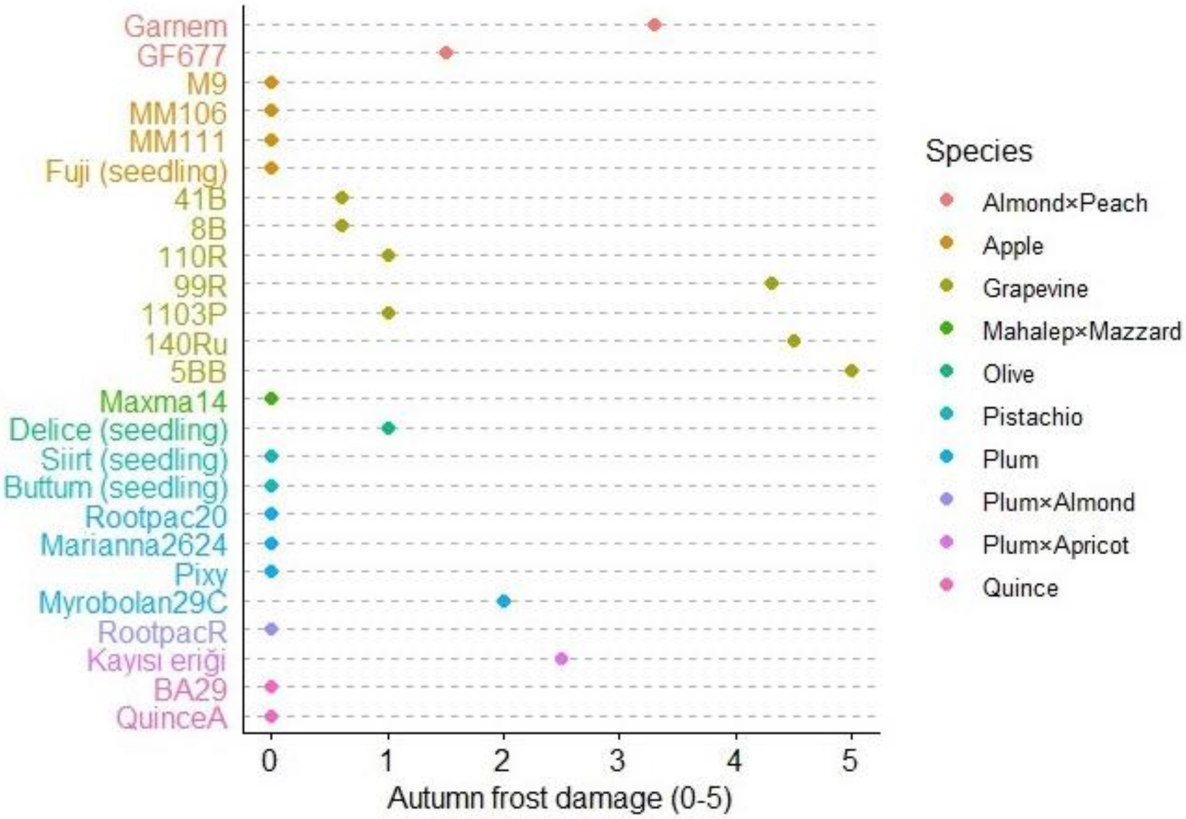

Figure 5. Damage degree of fruit and grapevine rootstocks after the autumn frost (The rating scale ranges from 0: no visible injury to 5: shoot system of plants damaged entirely by autumn cold).

mulberry, pistachio, pear, sweet cherry, sour cherry, apple, Plum × Almond, and Mahaleb × Mazzard cultivars and rootstocks (Figure 4 and Figure 5).

In consideration of the plant genotype's significance in determining potential frost resistance (Tromp, 2005), it is not surprising that differences in freezing tolerance can be substantial, not only between fruit and grapevine species but also within species among different cultivars and rootstocks. However, the survival of acclimatized woody tissues of fruit trees at low temperatures has received much less attention than flower buds, and limited information is available (Janes and Kahu, 2008; Neuner et al., 2019; Repo et al., 2021). Moreover, the situation in newly planted fruit and grapevine species is even more complicated since some parts of trees do not harden and may continue growth during the autumn. Mature plants acquire cold hardiness through cold acclimation, known as a seasonal increase in overwintering perennials' freezing tolerance (Arora and Taulavuori, 2016). Therefore, mature trees' responses to low temperatures may not accurately reflect the response of juvenile plants (Wolkovich et al., 2012; Vitasse, 2013; Lim et al., 2014). It is essential, therefore, that the capability of each separate scion/rootstock combination to harden and tolerate cold temperatures should be tested after planting in local environmental conditions.

In this study, cold injury was observed in fifteen of the 29 examined species during autumn. Among them, young trees of fig, persimmon, walnut, and chestnut cultivars were classified as very susceptible under unfavorable autumn conditions. Cold damage after planting is increasingly common in these species under our conditions. Factors such as water content, starch, and soluble carbohydrates at the onset of frost hardening could explain most of the temporal variability in frost resistance (Poirier et al., 2010; Charrier and Améglio, 2011), with their activity usually related to hardening (Améglio et al., 2004; Morin et al., 2007; Zuther et al., 2012). It is likely that the hardening process in these four species was more affected by erratic temperature fluctuations during the early phase of hardening, as the speed of hardening is closely related to temperature changes (Pogosyan and Sakai, 1969; Charrier et al., 2011).

Olive, the only evergreen species examined in this study, demonstrated robust autumn cold hardiness, surpassing that of most fruit and grapevine species. According to farmers' experiences, olive cultivars grafted on Delice seedling rootstock exhibit higher cold resistance, especially in the first 10 years after planting, compared to those grown on their own roots. Thus, the Gemlik olive cultivar used in our study is grafted onto Delice seedling rootstock. Additionally, higher leaf density and cell wall rigidity were observed in olive at lower temperatures (Arias et al., 2015), which may enable it to cope with sub-zero temperatures during winter.

Autumn frost damage, based on tissue browning, was determined for seven grapevine rootstocks with the order of cold resistance as follows: 41B > 8B > 110R > 1103P > 99R > 140Ru > 5BB (Figure 5). It was observed that grapevine rootstocks that continued their growth until the end of the season were more damaged by early autumn frosts. Although the mechanisms underlying grapevine cold tolerance remain largely unknown, phytohormones (e.g., ABA, ethylene, JA), metabolites (e.g., soluble sugars, proline, ascorbate), photosynthesis, and molecular changes associated with physiological changes play crucial roles in the cold response of grapevines (Ren et al., 2023).

No cold damage occurred in fourteen of the 29 examined species during unfavorable autumn conditions, and the examined cultivars and rootstocks belonging to these species were classified as cold-tolerant based on freezing injury indexes. The acquisition of plant cold tolerance results from highly complex physiological and biochemical processes, including the composition, structure, and function of the cell membrane (Dominguez et al., 2010; Arisz et al., 2013), hormone signal transduction, and the synthesis of soluble sugars, proteins, and other osmotic regulatory substances (Tauzin and Giardina, 2014; Shi et al., 2015). It also involves enhancements of antioxidative mechanisms and changes in lipid and protein composition (Gusta and Wisniewski, 2013). Despite significant advances in understanding the biochemical activities and molecular mechanisms of some plants, our knowledge of the cold response in fruit trees and grapevines remains fragmented, and the applicability of knowledge from different species to temperate species is yet to be determined (Mukhopadhyay and Roychoudhury, 2018; Ren et al., 2023). Identifying variations involved in cold tolerance would enhance our understanding of the complex mechanisms of plant adaptation to stress.

4. Conclusions

As a consequence, projected climate change is expected to significantly impact the cold hardiness of fruit and grapevine species in the Lake Region, presenting a substantial challenge for agriculture. The increasing frequency of temperature fluctuations and erratic episodes of unseasonal warming under changing climatic conditions have already led to a loss of hardiness, with autumn frost damage in our study being attributed to such events. Our findings suggest that freezing injury can be particularly detrimental, especially to newly planted fruit and grapevine species, during autumn temperature fluctuations. Young trees of fig, persimmon, walnut, chestnut, almond, hazelnut, and hawthorn cultivars, as well as almond × peach, plum × apricot, and grapevine rootstocks, experienced varying levels of cold damage. Integrating the evaluation of freezing injury with horticultural practices will be crucial to ensuring the successful cultivation of temperate fruit and grapevine species. We stress that the quality of nursery trees and improved hardening conditions in the fall could be key factors in reducing plant vulnerability to freezing injury. These results can inform orchard management practices and aid in assessing climate and weather risks in new production areas.

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