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An exothermic process involved in the late spring frost injury to flower buds of some apricot cultivars (*Prunus armenica* L.)

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ABSTRACT

Freezes during early spring can injury flower buds of apricot (*Prunus armeniaca* L.). The reduction in apricot production owing to cold injury to flower buds can be significant and serious problem for apricot growers and is common and among commercial production in some regions of the Turkey. Therefore, in this study, using Differential Thermal Analysis (DTA), freezing point (FT, LTEs), and/or freezing injuries in flower buds were determined at different development stages, such as first white, first bloom, and full bloom. Some domestic and foreign apricot cultivars tested were Hasanbey, Hacıhaliloğlu, Şekerpare, Erzincan Tokaloğlu, Mihralibey, Şalak and Roksana. With the development of flower buds, the frost tolerance of buds decreased, which indicates that their freezing point increased, and the frost tolerance of buds changed according to different phonological stages and apricot varieties. Additionally, cold tolerance of flower buds gradually decreased while their sensitivity to first white, first bloom and full bloom temperatures increased. The apricot cultivars were classified as hardy (Hacıhaliloğlu and Şalak), moderately hardy (Hasanbey, Şekerpare and Roksana) and least hardy (Erzincan Tokaloğlu and Mihralibey). The evidence illustrates that this investigation will provide a better comprehension of apricot frost tolerance and will assist to apricot growers in decision-making of frost control practices.

1. Introduction

Turkey is an important apricot producer due to its suitable geomorphological and climatic conditions (Ercisli, 2009; Nazemi et al., 2016). However, one of the most important problems which has effects on apricot growing in Turkey is the early flowering of varieties and coincidence of their bud burst times with a frost spring (Gunes, 2006; Moghadam and Mokhtarian, 2006). Thus, frost injury might cause huge yield loss or even be a limiting factor to growing apricots (*Prunus armeniaca* L.) in northern latitudes, where critically late spring frost can occur (Rodrigo, 2000; Gunes, 2006). In particular, after bud burst, the temperatures below freezing during and the frequency of frosts in early spring has the potential to not only damage buds but also flowers, small fruits and shoots (Smeeton, 1964; Salazar-Gutiérrez et al., 2014). Additionally, late spring frost is a significant problem for the apricot species that are particularly prone to erratic productions (Layne et al., 1996).

Rapid and reliable measurement methods are playing an indispensable role in determination of late spring frost tolerance level of the apricot varieties which has a positive correlation in terms of scientific and economic reasons (Nazemi et al., 2016). For this purpose, many measurement techniques (Differential Thermal Analysis, Nuclear Magnetic Resonance, Infrared Video Thermography, Magnetic Resonance Imaging, Low Temperature Electron Microscope, Differential Scanning Calorimeter, Tripheny Tetrazolium Chloride Reduction, Electrical Conductivity, Tissue Browning) developed in order to understanding the mechanism of cold hardiness in the plants expose to low temperatures below freezing point (Yadava et al., 1978; Quamme, 1991; Pearce, 2001; Fennell, 2004; Mills et al., 2006; Kaya and Köse, 2017). There are advantages and disadvantages with respect to each of the methods used for different purposes. On the other hand, there are shortcomings in statistical relationships between commonly used tests such as tripheny tetrazolium thloride reduction test, electrical conductivity test, germination and tissue brown test, which have quick, easy, inexpensive and peculiar critical values in viability estimates but with these tests it is determined whether or not there is death in the parts of the plant tissue that are only exposed to the test. Whereas, it was not very clear to understand which temperature level causes to plant tissues dead and it is not quite practical to make an investigation on several samples. However, differential thermal analysis (DTA), one of these measurement techniques, is commonly used in determining frost tolerance of tissues and organs that avoid freezing by supercooling, such as floral

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buds of peach (Durner and Gianfagna, 1991; Quamme, 1978), cherry (Salazar-Gutiérrez et al., 2014), buds of grapevine (Andrews et al., 1984; Quamme, 1986; Wolf and Pool, 1987), pear (Montano et al., 1987), apple (Quamme et al., 1972a; Salazar-Gutiérrez et al., 2016), and azalea (Graham and Mullin, 1976).

Investigations about spring frost tolerance of reproductive organs of apricot cultivars using DTA are limited. The tolerance level through early spring for new apricot cultivars has not been well characterized and is lesser known about the cold hardiness of new apricot cultivars. Therefore, there is need to determine the frost tolerance of commercial apricot cultivars using suitable measurement techniques. The overall objective of this research was to detect the change in cold tolerance of apricot flower buds through different phonological phases for different apricot cultivars using DTA and temperature-controlled laboratory-based freezing technique.

2. Materials and methods

2.1. Plant material

Spring frost tolerance was detected in flower buds among some domestic and foreign cultivars such as Hasanbey, Şalak, Erzincan Tokaloğlu, Mihralibey (a late-maturing cultivar), Roksana, suitable for the fresh market, Hacıhaliloğlu, suitable for drying, and Şekerpare, suitable for the jam and the fresh market. The apricot varieties were grown at an experimental orchard located at the Horticultural Research Institute in Erzincan, Turkey. Trees grafted on apricot seedling rootstock were trained as free palmette (6 × 6 m) with rows facing east-west. Apricot varieties analyzed when they were all 15 years old. Additionally, the pruning, plant protection, fertilization and drip system irrigation were carried out in the same way for all cultivars. In study, spurs were collected from three randomly chosen trees for each cultivar, and at least ten representative shoot cuttings (25–30 cm in length from intermediate sections of the spurs) per each varieties were collected at different development stages (in first white, first bloom, and full bloom). The shoot sections were placed in polyethylene bags, and transferred to the laboratory as soon as possible. Then, flower buds on spurs were used for DTA analysis and a controlled freezing test were determined for the apricot cultivars during the early spring season of 2016–17.

2.2. Differential thermal analysis

The DTA analysis on apricot flower buds was conducted on one set of samples. The method used in this study was similar as defined by Mills et al. (2006) and Salazar-Gutiérrez et al. (2014). For DTA, each set of flower bud samples were included of 9 replicates per cultivar a total of six flower buds were used each development stages per replication. Sample chamber consisted of a tray and each tray included nine wells. The apricot flower buds were placed directly into each thermoelectric module (TEMs, Melcor, Trenton, NJ), for a total of 54 buds per cultivar. Silicone grease was utilized to facilitate contact between the flower buds and TEMs. Each tray lid was tightened and then the trays were placed into a programmable freezer chamber, the Tenney Junior Environmental Test Chamber (model TU-JR, Thermal Product Solutions, Williamsport, PA), equipped with a temperature controller, (Partlow MIC 1462, The Partlow West Company, New Hartford, NY) to reach a stable cooling rate that was 4 °Ch^{-1}. The freezer chamber was programmed to keep at 4 °C during 1 h, decline to −32 °C in 9 h (a cooling rate of 4 °C/hr), then back to 4 °C in 10 h (a warming rate of 4 °C/hr). Four trays (thirty-six TEMs) were loaded in each run of the freezer chamber. The data acquisition system recorded the latent heat of fusion (voltage signal) released when supercooled flower bud tissues freeze for each TEM (Andrews et al., 1984; Mills et al., 2006; Salazar-Gutiérrez et al., 2016). The data acquisition system (Delphin Expert Key 200 L, Data Acquisition System) recorded instantly signals from each TEM and transferred voltage signal directly to Excel spreadsheet. The flower bud exotherms were determined plotting the TEM outputs (volts) against the temperature (∘C). Lethal temperatures for apricot flower buds were reported as LTE_{25}, LTE $_{50}$, and LTE $_{75}$ the temperatures at which 25%, 50%, 75% of flower buds were killed (Kaya, 2018).

2.3. Statistical analysis

LSMeans Student's *t*-test was used to detect that mean values of measurement parameters were significantly different between apricot cultivars within each development stages with a level of importance $p \le 0.01$. We used JMP statistical software (version. 7.0, SAS Institute Inc., Cary, NC).

3. Results

This investigation has done during two years (2016–2017) and because data were not same, therefore, founds for both years have separately shown. Exothermic events were determined in the differential thermal analysis (DTA) profiles for apricot flower buds within the temperature range that was used, i.e., 4∘C to −32∘C, and for different development stages. The DTA analysis showed temperature exotherms, which are generally interpreted as frozen caused by water in the extracellular and intracellular areas. But, the high and low temperature exotherms (HTEs and LTEs) were identified simultaneously for apricot flower buds at different stages of development. Significant differences in lethal temperatures (LTE_{50}) were found between apricot cultivars for the different sampling date during both seasons as illustrates in 2016 (Figs. 1,3,5) and 2017 (Figs. 2,4,6). In all apricot cultivars, flower bud $LTE_{25,\ 50,\ 75}$ decreased with the overall trend of increasing temperatures from first white period through full bloom period for both years (Figs. 1–6).

During the first white period of 2016, Hasanbey, Şekerpare, Hacıhaliloğlu and, Şalak showed the highest cold hardiness ($LTE_{25,\ 50,\ 75}$), while Erzincan Tokaloğlu and Mihralibey were the least hardy cultivars in this development stage (Fig. 1). This profile changed according to the cultivars at the first white period of 2017. In 2017, Hacıhaliloğlu and Şalak showed the highest LTEs, Şekerpare, Roksana and Hasanbey showed an intermediate cold hardiness, while Mihralibey and Erzincan Tokaloğlu were the least hardy cultivars in this development stage (Fig. 2).

We detected that the initial freezing temperatures (LTE_{50}; from high to low) occurred in cultivars Şalak > Hacıhaliloğlu > Şekerpare > Roksana > Hasanbey > Mihralibey > Erzincan Tokaloğlu; the sequence of cultivars with complete flower bud freezing temperatures resulting in death (LTE_{25}; from high to low) was (−9.95 °C) Şalak > (−8.57 °C) Hacıhaliloğlu > (−6.85 °C) Şekerpare > (−5.17 °C) Roksana > (−5.08 °C) Mihralibey > (−4.11 °C) Erzincan Tokaloğlu > (−4.01 °C) Hasanbey; the sequence of cultivars with complete flower bud freezing temperatures resulting in death (LTE_{75}; from high to low) was (−11.17 °C) Hacıhaliloğlu > (−10.74 °C) Şalak > (−9.93 °C) Şekerpare > (−9.02 °C) Hasanbey > (−7.71 °C) Roksana > (−6.00 °C) Mihralibey > (−5.05 °C) Erzincan Tokaloğlu during the first bloom period of 2016, by comparing the initial freezing temperatures of flower buds in different cultivars (Fig. 3). We identified that the initial freezing temperatures (LTE_{50}; from high to low) occurred in cultivars Hacıhaliloğlu > Şalak > Hasanbey > Roksana > Mihralibey > Şekerpare > Erzincan Tokaloğlu; the sequence of cultivars with complete flower bud freezing temperatures resulting in death (LTE_{25}; from high to low) was (−9.74 °C) Hacıhaliloğlu > (−9.17 °C) Şalak > (−5.93 °C) Hasanbey > (−4.93 °C) Roksana > (−4.71 °C) Mihralibey > (−4.32 °C) Erzincan Tokaloğlu > (−5.57 °C) Şekerpare; the sequence of cultivars with complete flower bud freezing temperatures resulting in death (LTE_{75}; from high to low) was (−11.04 °C) Şalak > (−10.67 °C) Hacıhaliloğlu > (−7.16 °C) Şekerpare > (−7.04 °C) Roksana > (−6.71 °C) Hasanbey > (−5.88 °C) Mihralibey > (−4.82 °C) Erzincan Tokaloğlu