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Interactive effects of temperature and genotype on almond (*Prunus dulcis* L.) pollen germination and tube length

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A R T I C L E I N F O

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A B S T R A C T

Some imperative developed genotypes of almond (‘Tardy Nonpareil’, ‘Nonpareil’, ‘Sahand’, ‘Rabie’, ‘Azar’, ‘Shekofeh’, ‘Sefied’ and ‘Mamaei’) were utilized in two experiments for 3 years to elucidate the genotype response of almond pollen germination and tube development at various temperature levels. Pollen was subjected to pre-incubation at 10, 20, 30 or 40∘C for 24 h to reproduce temperature stress during pollen dispersal; and then *in vitro* cultured. In the second examination, pollen was exposed at 15, 20, 25 or 30 °C for 24 h in vitro to assess pollen reaction in state of water and supplements accessibility and to determine the ideal pollen germination and tube development temperatures for every genotype. The most elevated pre- incubation temperature treatment (40 °C) completely prevented pollen germination in “Mamaei” and ‘Sefied’, while even in the less influenced cultivars ('Shekofeh’, ‘Azar’, ‘Rabie’, ‘Sahand’, ‘Tardy Nonpareil’ and ‘Nonpareil’) germination rates were as low as 2–3%. Pre-incubation at 30 ∘C or 40 °C negatively affected pollen germination and pollen tube length. In the second experiment, *in vitro* pollen germination increased after incubation at 25 °C for ‘Mamaei’ (+2%), ‘Sefied’ (+3%), ‘Shekofeh’ (+3%), ‘Azar’ (+3%), ‘Rabie’ (+4%), ‘Sahand’ (+5%), ‘Nonpareil’ (+5%) and ‘Tardy Nonpareil’ (+5%) compared to the control (20∘C). At 30 ∘C, germination percent for ‘Mamaei’, ‘Sefied’, ‘Shekofeh’, ‘Azar’, ‘Rabie’, ‘Sahand’, ‘Nonpareil’ and ‘Tardy Nonpareil’ was 35, 35, 10, 15, 25, 15, 35, and 20% lower, respectively, compared to the control (20 ∘C). Pollen tube length additionally increased with incubation temperature for all of the considered genotypes. In view of the cumulative stress response index (CSRI) that was calculated for high temperature stress the developed genotypes were arranged: ‘Shekofeh’ and ‘Tardy Nonpareil’ as tolerant and ‘Nonpareil’, ‘Rabie’ and ‘Sahand’ as intermediate at 40 ∘C, while ‘Azar’, ‘Rabie’, Sahand’ and ‘Tardy Nonpareil’ as tolerant, ‘Shekofeh’ and ‘Nonpareil’ as intermediate and ‘Mamaei’ and ‘Sefied’ as sensitive at 30 °C. The observed strong genotype differentiated reaction in high and low temperature stress could be utilized by plant breeders towards producing new tolerant almond genotypes.

1. Introduction

Fruit growing is one of the important and paying branches of horticulture and has been practiced in most of the countries in the world since centuries. It is one of the important income sources of main fruit growing countries. Fruit species have been used not only for nutrition purposes but also to meet personal and social needs such as curing diseases, beautifying the planet etc (Hegedus et al., 2010; Canan et al., 2016; Sorkheh and Khaleghi., 2016; Zorenc et al., 2016).

Almond (*Prunus dulcis* Miller [D. A. Webb] syn. *P. amygdalus* Batsch) is one of the most widely established tree nut crops and today represents the biggest production of any commercial tree nut product. Almond trees grow in areas of the world that are described as having a subtropical Mediterranean climate with mild wet winter and warm, dry summer (Kester and Gradziel, 1996). In 2014, world production of almond was roughly 2,697,209 tones, of which Iran delivered 111,936 tones (FAO STAT Data sources, 2017).

There is a favorable temperature range for the distribution,

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Table 1
Almond genotypes assayed including the origin, pedigree and main agronomic traits.

Genotypes	Main agronomic traits				
	Origin	Lineage	Shell	Compatibility	Flowering[a]
Tardy Nonpareil	USA	Mutant of Nonpareil	Soft	Self-incomp.	Very late (+8 and later)
Nonpareil	USA	Unknown	paper	Self-incomp.	Middle (0 to +2)
Sahand	Iran	Unknown	Hard	Self-incomp.	Middle (0 to +2)
Rabie	Iran	Unknown	Hard	Self-incomp.	Middle (0 to +2)
Azar	Iran	Ai × Cristomorto	Semi-hard	Self-incomp.	Late (+5 to +7)
Shekofeh	Iran	Ai × Nonpareil	Semi-hard	Self-incomp.	Late (+5 to +7)
Sefied	Iran	Unknown	Soft	Self-incomp.	Early (-6 and earlier)
Mamaei	Iran	Unknown	Hard	Self-incomp.	Middle (0 to +2)

[a] The numbers in the parentheses indicate the days before (−) or after (+) peak "Nonpareil" bloom (Asai et al., 1996, Almond Production Manual. University of California. ANR Publication).

adaptation and productivity of wild and domestic plants. Minor deviation of temperature out of this range even for a short period may have an impact on the biochemical and physiological processes of plants (Kafizadeh et al., 2008). Some indicative plant functions that are affected by temperature are the vegetative and reproductive growth, nutrient absorption, protoplasmic movement, photosynthesis, respiration, metabolism, flower growth, fertilization, fruit maturation and seed quality (Guy et al., 2006, 2008; Koubouris et al., 2015a).

The most important role for the survival and the prosperity of living beings constitute the natural conditions. For example, adverse climatic changes such as the anticipated temperature increment of 0.5–4.5 °C (Met Office, 2007) for the foreseeable future and up to 6.4 °C till the end of the century (IPCC, 2007) can affect plant growth and reproduction. Also biodiversity can be influenced by potential changes in the extremes of climatic parameters (GBSC, 2007).

Plants grown outdoors are more sensitive to abiotic stresses since they are specifically exposed to extreme weather incidents. In almond production, most of the variability between years is considered to be due to the occurrence of frosts (Alonso Segura et al., 2017). In many plant species, ideal temperature for reproductive processes is lower than for vegetative development (Chen et al., 1982; Baker and Allen, 1993; Mitchell et al., 1993). Furthermore, the effect of temperature on pollen growth is genotype depended (Koubouris et al., 2009). In previous studies, heat stress commonly reduced pollen germination in plants (Kakani et al., 2002; Kafizadeh et al., 2008; Koubouris et al., 2015b).

Reproductive development in plants is more sensitive to high temperatures than vegetative development since plant richness is extensively diminished as temperatures increment (McWilliam, 1980). Fruit set and fruit development appeared to decrease fundamentally at day/night temperatures of 30/25 °C in cherimoya (Higuchi et al., 1998), 33/22 °C in groundnut (Prasad et al., 2001), and 35/15 °C in Brassica (Angadi et al., 2000). For heat-sensitive plants such as tomato, no fruit set occurs at day/night temperatures of 35/23 °C (Abdul-Baki and Stommel, 1995). Previous studies on cowpea (Hall, 1992), basic bean (Gross and Kigel, 1994), and peach (Kozai et al., 2004) demonstrated that elevated temperatures during flower development can significantly reduce fruit set. The decrease in fruit set has generally been credited to low pollen viability and germinability at high temperatures in several crop species (Sato et al., 2000; Prasad et al., 2001; Porch and Jahn, 2001). Such differences have enabled researchers to group cultivars into either heat-tolerant or heat-sensitive types. High temperatures over 30 °C are known to decrease fruit size (Wang and Camp, 2000), fruit weight (Kumakura and Shishido, 1994), and general plant development (Hellman and Travis, 1988).

The major cultivars grown in Iran are 'Mamaei', 'Sefied', 'Rabie', 'Shekofeh' and 'Azar', but because these are self-incompatible (Moradi, 2005; Sorkheh et al., 2010), pollinizer cultivars such as 'Rabie', 'Sahand' and self-grown seedling genotypes are commonly included in orchards. However, the impact of temperature stress on pollen germination has not been fully studied until now. Pinney and Polito (1990) explored the impact of temperature (−20 °C) during storage on olive pollen performance. Increase of temperature commonly causes decrease in air relative humidity. When this phenomenon occurs gradually and in smaller gradient, partial dehydration allows pollen for adapting without serious damage to the cytoplasm (Bassani et al., 1994). In contrast, severe and fast temperature rise leads to pollen death (Pacini, 1996). Pollen demands for nutrients and water are fulfilled by the anther before dispersal. Similarly, during the last phase of pollination when pollen grains land on the stigma, it is the mother tissue of the stigmatic surface that nurtures the pollen grains which are favored by the humidity of the stigmatic surface, in order to survive and complete fruit set, the ultimate goal for plant reproduction. In contrast, it is the phase in-between, i.e. pollen dispersion, that pollen is exposed to a series of abiotic stressors −temperature, drought, excessive sunlight, UV-B radiation- that may affect its subsequent germinability.

The aim of the present study was to assess the impact of temperature on pollen germination and tube development under various relative humidity levels. Besides, we elucidated the response of eight almond cultivars of major worldwide importance to high and low temperature stress conditions and characterized genotypes for relative tolerance according to the cumulative stress response index.

2. Materials and methods

2.1. Plant material and growth conditions

The plant material analyzed was obtained from the Institute of Agriculture and Natural Resources Research Center of Shahrekord (A.N.R.R.C.) in Shahrekord, Iran. The name, origin and other fundamental agronomic characters of the 8 studied genotypes ('Tardy Nonpareil', 'Nonpareil', 'Sahand', 'Rabie', 'Azar', 'Shekofeh', 'Sefied' and 'Mamaei') that were growing at the 'Emamieh' orchard Collection, A.N.R.R.C., Charmahal Va Bakhtiari, Iran, are reported in Table 1.

Flowering of the eight genotypes occurs between mid March and mid May depending on each year's temperature levels during the preceding winter–spring season. Monthly means of daily temperature and relative humidity are presented in Table 2. Data were collected from the meteorological station of A.N.R.R.C., at Shahrekord, Iran. In each year, 10 flowers from each of 10 trees of the eight almond cultivated genotypes were collected at flower growth stage 'D' (Felipe, 1977; Egea et al., 2004) and pollen was stored at 4 °C and used in the next 2–3 days.

Table 2
Monthly means of daily temperature and relative humidity, in Shahrekord area of Southern Iran, from March to May for the years 2014–2015.

	March	April	May
Temperature (°C)	11.2	15.8	20.7
Relative humidity (%)	55	48	42