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Phenological characteristics of walnut (*Juglans regia* L.) genotypes under environmental conditions of Karaj in Iran

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ABSTRACT

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Walnut (*Juglans regia* L.) is one of the most important horticultural crops grown in Iran. To characterize the phenology of walnut genotypes in different seasons and its relationship with climatic conditions, this study was carried out in temperate fruits research center of Horticultural Science Research Institute, Karaj, Iran. The phenological characteristics of 39 selected superior walnut genotypes were compared with Chandler, Jamal and Rond de Montignac cultivars during 2012-18. The results showed that the overall average leafing dates of genotypes varied from March 15-29 over seasons. 'Z16' had the earliest leafing date (March 13) together with 'Kr95'and high variation (24 and 25 days, respectively). Latest leafing date (April 13) and least variation (four days over seasons) belonged to 'Ronde de Montignac'. The average leafing dates in 'Chandler', '88-1, '88-2' were in April 6-8. The average pollen shedding, in different seasons, started in genotypes from March 29 to April 12. While the average of pistillate flowers receptivity varied from April 2 to April 11. The effect of season was not significant on nut ripening. The overall average fruit ripening was on August 24-25 in different seasons. However, the ripening dates for walnut genotypes varied from August 15 in 'Kr111' to September 16 in 'Chandler'. The temperature of March showed to have a crucial effect on bud break, catkin development, pollen shedding, and pistillate flowers development and receptivity period. Leafing date showed to be more affected by season in comparison to other phenological characteristics. The leafing dates varied 5.5 and 2.8 days, with 1 °C increase in average temperature, in early and late leafing genotypes, respectively.

Keywords: walnut, climatic conditions, flowering, fruit ripening, leafing date

INTRODUCTION

Iran with different eco-geographical regions is one of the major diversity centers for Persian walnut in the world (Ramos, 1998). Most of walnut orchards in Iran are originated from seedling trees and widely distributed on borders of agricultural lands or in valleys. Using of walnut genotypes for thousands of years have led to the high genetic diversity in different regions (Eskandari *et al.*, 2006; Hassani *et al.*, 2014; Rezaei *et al.*, 2018).

The poor quality of walnut production, because of genetic variation in seedling trees, usually decreases the market value (Eskandari *et al.*, 2006; Hassani *et al.*, 2012). Despite the diversity related problems, the genetic segregation provides opportunities for selection of superior genotypes for introduction of new cultivars (McGranahan and Leslie, 2006; Asma, 2012; Hassani *et al.*, 2014; Rezaei *et al.*, 2018).

Despite of historical cultivation of walnut species (*Juglans* spp.), walnut breeding programs initiated in 20th century by using different breeding schemes, from conventional breeding to the most recent advances in genomic techniques (Bernard *et al.*, 2018; Mahmoodi *et al.*,2019). The precision characterization and identification of suitable walnut genotypes is a basic requirement for the management and usage of germplasm for applied breeding purposes (Ruiz-Garcia, 2011).

Morphological traits are important for germplasm characterization, and therefore must be evaluated and recorded in the early steps of selection (Radivojevic *et al.,* 2014). Characterization of plant phenology can be as vital tool for ecosystem simulation models and for predicting the response of ecosystems to climate change (Chuine *et al.,* 2016). The temperature is the most important environmental factor affecting the time of occurrence of phenological stages in plants (Cleland *et al.*, 2007). Meanwhile, in plant species the interaction between genetics and environmental temperature is an important determinant of plant phenology (Springate and Kover, 2014).

With increasing the temperature, leafing time significantly occurs earlier in walnut cultivars. Increasing temperature, by rapidly increasing the amount of heat accumulation, accelerates the bud break and the start of pistillate flowers receptivity. In late leafing walnut genotypes, the amount of heat requirement (growth degree hour, GDH) was significantly higher than early leafing genotypes and this delayed the bud break of these genotypes (Hassankhah *et al*., 2017). Fallahi *et al*. (2014) showed that the effect of different seasons on early and late flowering nectarine cultivars were not similar. In the cooler seasons, the differences were greater than warm seasons.

The important phenological characteristics of walnut including leafing time, pistillate flowering and catkin shedding period, fruit ripening, harvest time and leaf fall usually are affected by environmental conditions. The use of genetic diversity for breeding of adapted cultivars with desirable bearing habit as well as superior fruit and kernel quality traits is an accepted strategy among walnut breeders. Many studies have been carried out to select promising genotypes based on late leafing and nut quality for different region in Iran (Arzani *et al.,*2008; Vahdati *et al.,*2009; Khadivi-Khub *et al.,* 2015; Mahmoodi *et al.,*2016; Rezaei*et al.,*2018). Primary evaluation and selection of walnut genotypes based on phenological and morphological traits carried out in other countries (Asma, 2012; Keles *et al.*, 2014; Akca *et al.*, 2015; Chand *et al*., 2017; Bernard *et al.,* 2018).

The effect of genotype and environment on occurrence of phenological stages in walnut has not been well documented. Identification, evaluation and selection of new late leafing, lateral bearing genotypes for tolerance to late spring frost and adaptability to climatic conditions have been carried out among native germplasm during the first decade of 2000 in several provinces of Iran. A preliminary report on the results of project has been published by Hassani *et al.* (2014).

Understanding of seasonal variation in phenological characteristics, especially leafing date, are very important for walnut adaptability. The main objective of this study was to characterize phenological characteristics of walnut genotypes during 2012-2018 seasons in Karaj, Iran.

MATERIALS AND METHODS

The plant material in this study were 39 walnut superior genotypes collected from Alborz, Qazvin, Zanjan, West Azerbaijan, Kerman, Khorasan-e-Razavi, Semnan and Yazd provinces in Iran and compared to Chandler, Jamal and Ronde de Montignac as control cultivars (Table 1). The grafted trees had been planted in two blocks in 7 × 7 m spaces with three trees per plot. The experimental orchard was established in 2006 in Meshkindasht, Karaj at 35°45′ N, 50°57′ E and 1240 meters above sea level. Data collection was carried out during 2012-18.

Table 1. List of walnut genotypes and collection provinces

Genotype	Province	Genotype	Province	Genotype	Province
321	Alborz	Kr117	Kerman	Or126	W. Azerbaijan
88-1	Qazvin	Kr118	Kerman	Or2	W. Azerbaijan
88-2	Qazvin	Kr1-25	Kerman	Or24	W. Azerbaijan
88-4	Qazvin	Kr132	Kerman	Or40	W. Azerbaijan
88-5	Qazvin	Kr1-40	Kerman	Or64	W. Azerbaijan
Ab7	Zanjan	Kr154	Kerman	Rond de Montignac	France
Chandler	California	Kr23	Kerman	Sh1	Semnan
G3	Alborz	Kr95	Kerman	Sh14	Semnan
Jamal	Alborz	Kr96	Kerman	T1	Alborz
K15	Alborz	Kz2	W. Azerbaijan	Unk1	Alborz
Z12	Alborz	Kz3	W. Azerbaijan	Yazd	Yazd
Z16	Alborz	Kz6	W. Azerbaijan	Z14	Qazvin
Kh33	Khorasan-e- Razavi	Kz8	W. Azerbaijan	Z28	Qazvin
Kr111	Kerman	N31	Qazvin	Z30K	Alborz

The phenological data including leafing date, first and last pollen shedding, pistillate flowers receptivity and fruit ripening dates were recorded during 2012-2018 seasons. Leafing date was recorded when green leaves emerged from 50% of terminal buds. The dates on which the first and last catkins started pollen shedding have been recorded as starting and ending of pollen shedding. The onset and conclusion of female flower receptiveness were recorded when the first and last order pistillate flowers were receptive.

When the packing tissues in most of nuts (more than 80%) completed browning, it was considered as the ripening time (IPGRI, 1994) (Fig. 1). The pollen shedding and pistillate flowers receptivity period obtained from the differences between the first and the last corresponding dates. Growing degree day (GDD) was calculated as proposed by Prentice *et al*. (1999). Cumulative growing degree days (GDD) were calculated for the leafing date, pollen shedding and pistillate flowers receptivity period (Fallahi *et al*., 2014). The chilling requirements were estimated by Utah Model (Richardson *et al*., 1974).

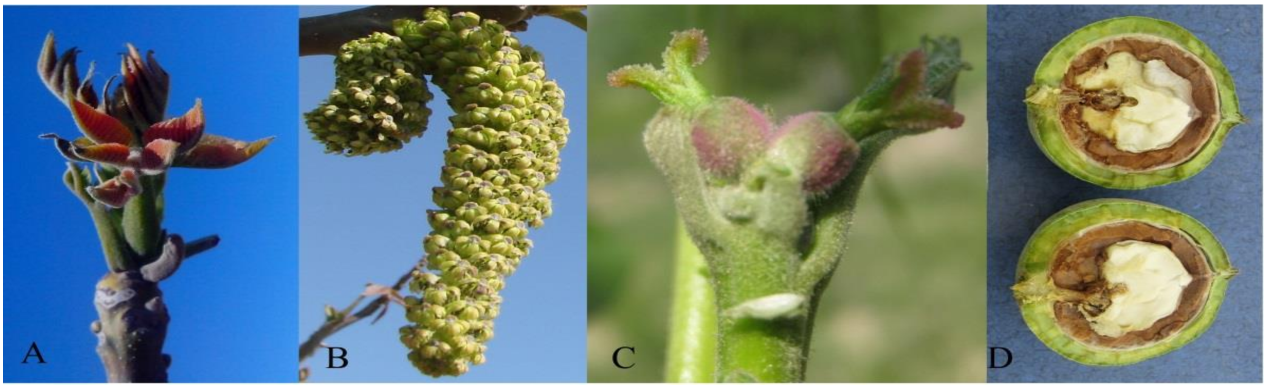

Fig. 1. Leafing date (A), start of pollen shedding (B), start of pistillate flowers receptivity (C), and nut ripening stage (D)

The meteorological data obtained from Karaj meteorological station and used to study the relationships between phenological characteristics and climatic information. The average of some monthly meteorological parameters over 2009-2018 are shown in Table 2.

Table 2. Monthly mean temperature, absolute maximum and minimum temperatures and precipitation in 2009-18) of Karaj meteorological station

Climatic factors	January	February	March	April	May	June	July	August	September	October	November	December	Mean/Total
Mean temperature (°C)	2.4	4.5	9.3	15.0	20.5	26.0	28.3	27.8	23.8	17.4	9.9	4.6	15.8
Absolute max. temp. (°C)	17.4	23.2	27.4	31.6	35.6	41.4	41.8	41.4	37.2	31.9	23.8	21.5	41.8
Absolute min. temp. (°C)	-12.6	-12.2	-7.0	-4.7	6.6	10.3	14.1	10.0	8.2	2.0	- 11.0	-7.4	-12.6
Precipitation (mm)	29.0	29.4	43.3	39.1	18.8	2.7	3.4	2.5	1.4	17.6	29.1	31.7	248.0

Combined analysis of variance was performed by mixed model in which seasons was random and genotypes fixed factors, respectively, using the data of four seasons (2015-18). Mean comparison was carried out using Duncan's Multiple Range Test (DMRT). For regression analysis, phenological data of walnut genotypes of 2012-18 seasons together with meteorological data were used. For analyses, the phenological data that collected as dates and were converted to days after the first of March for leafing, pollen shedding, pistillate flowers receptivity. For calculating the fruit ripening time of walnut genotypes the number of days after March 20 and the number of days after the end of female flowers receptivity were used in each season.

RESULTS AND DISCUSSION

Analysis of variance of data showed that the effect of season, genotype and their interaction were significant ($P < 0.05$) on leafing time, start and duration of both pollen shedding and pistillate flowers receptivity. Effect of season was not significant on ripening time, while the genotype and genotype × year interaction effects were significant ($P < 0.05$).

Regarding the differences in average leafing dates of walnut genotypes in different seasons, the earliest leafing date was observed in 2016 on March 15 and the latest in 2017 on March 29. Similar variations were observed in first pollen shedding and first pistillate flowers receptivity. The average of pollen shedding start was varied from March 29 to April 12 in different years, while the average of female flowers receptivity start changed from April 2 to April 11 (Fig. 2).

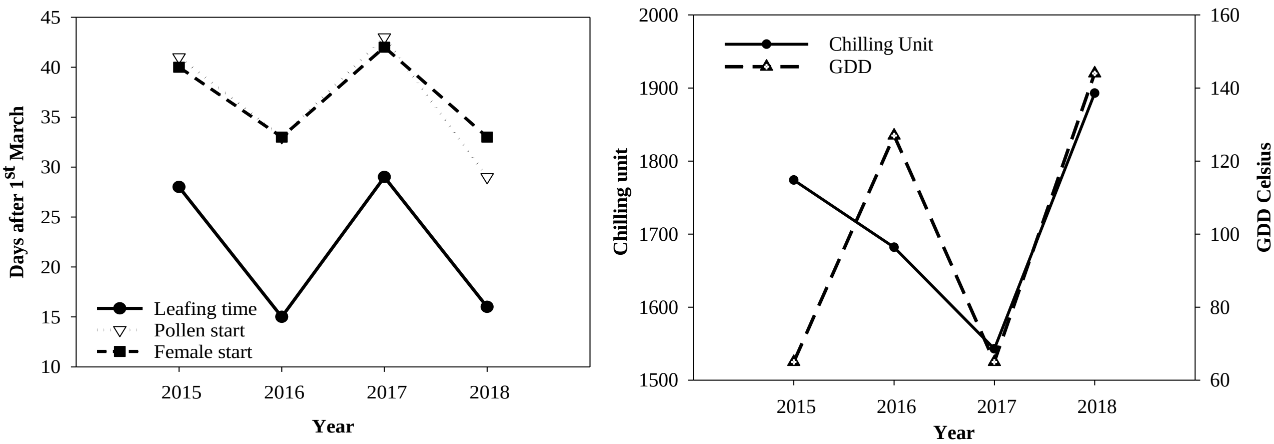

Fig. 2. Mean of leafing time, first pollen shedding and first pistillate flowers receptivity of walnut genotypes (left), winter chill units (Utah) and GDD of March (right)

Researchers have showed that phenological characteristics are strongly affected by climatic conditions (Rezaei *et al.*, 2018) and temperature is the main climatic factor affecting the phenological traits (Chuine *et al.*, 2016).

In this study, the calculated GDD from the March 1 was the important parameter for determining the start of growth. There were highly negative correlation between the temperature of March and leafing date, start of pollen shedding and pistillate flowers receptivity (r = -0.97**, r = -0.98** and r = -0.97**, respectively). These results were in agreement with the findings of Mariana and Niculina (2017).

These results of the present study are in agreement with the findings of Hassankhah *et al*. (2017) who showed leafing time, start of male and female flowers in walnut were highly correlated with GDD. In the studies of Aslani Aslamarz *et al*. (2009 and 2010), late leafing cultivars had higher GDD than early leafing ones. The regression analysis revealed that, if the average temperature of the January and February were lower than 3 °C, it would led to delay in leafing time. With increasing temperature of this period from 3 °C to 8° C, the leafing time occurs 2-3 days earlier (Fig. 3).

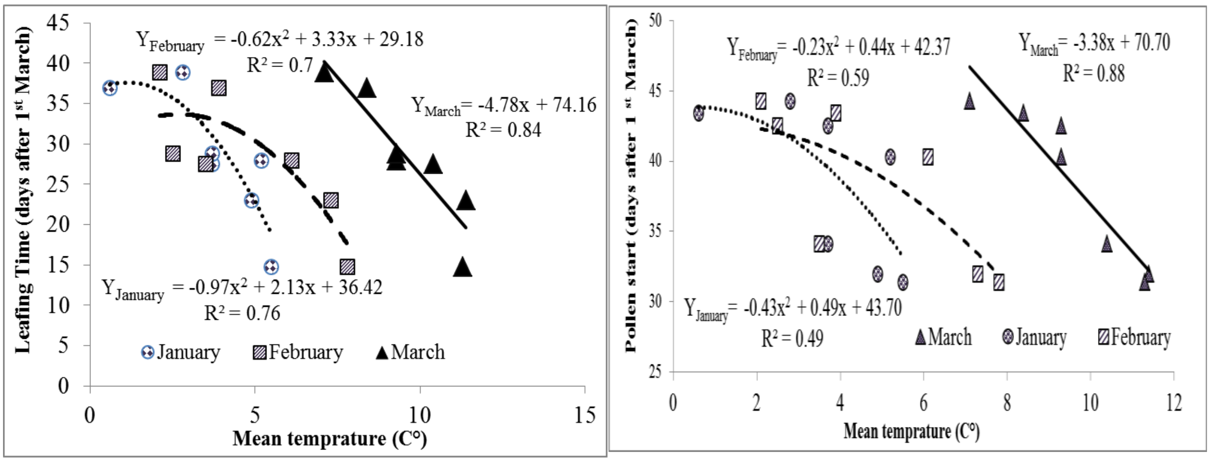

Fig. 3. Regression between mean temperatures of January, February and March with mean leafing time and first pollen shedding

The coefficient of determination between average temperature of March with leafing time, first pollen shedding and pistillate receptivity were R^2 = 0.84**, R^2 = 0.88** and R^2 = 0.82**, respectively. Based on the results, with increase of 1°C in the average temperature of March, the average time for leafing, first pollen shedding and first pistillate flowers occurred earier by 3-5 days (Fig. 3). The average temperature of January and February had strong relationship with leafing time (R^2 = -0.76** and R^2 = -0.7**, respectively). However, the same relations were observed for the first male and female flowering.

The average of leafing time among genotypes differed 29 days between 'Z16' as the earliest genotype (March 13) and 'Ronde de Montignac' as the latest (April 11). These results were in agreement with the findings of Hassankhah *et al*. (2017) who reported that the bud break was varied from March 16 to April 13.

Based on leafing data, the walnut genotypes were divided into five groups. The earliest group comprising of eight genotypes (Z16, N31, Kr111, Kr118, Kr132, Unk1, Kr95 and Or64) started to grow during March 14-18. The second group with 16 genotypes (Or126, Z12, Or24, Sh14, Z14, Kr154, K15, Sh1, Kr1-25, Kr96, 88-4, Z28, Or2, Z30K, 321 and Or40) were early-medium with the bud burst from March 19-21. The third group was including 13 genotypes that had medium leafing time and started to grow during March 21-27.

'Jamal' and two promising genotypes G3 and Kz3 as well as genotypes Ab7, Kz6, Kz8, Kh33, Kr1-40, Kz2, 88-5, T1, Kr117 and Kr23 classified in medium leafing group. The leafing time for the fourth group was April 4- 7. This group was consisted of 'Chandler' and two other promising genotypes '88-1' and '88-2' as well as Yazd genotype. Among all genotypes, cv. Ronde de Montignac was very late leafing and classified in fifth group (Fig. 4).

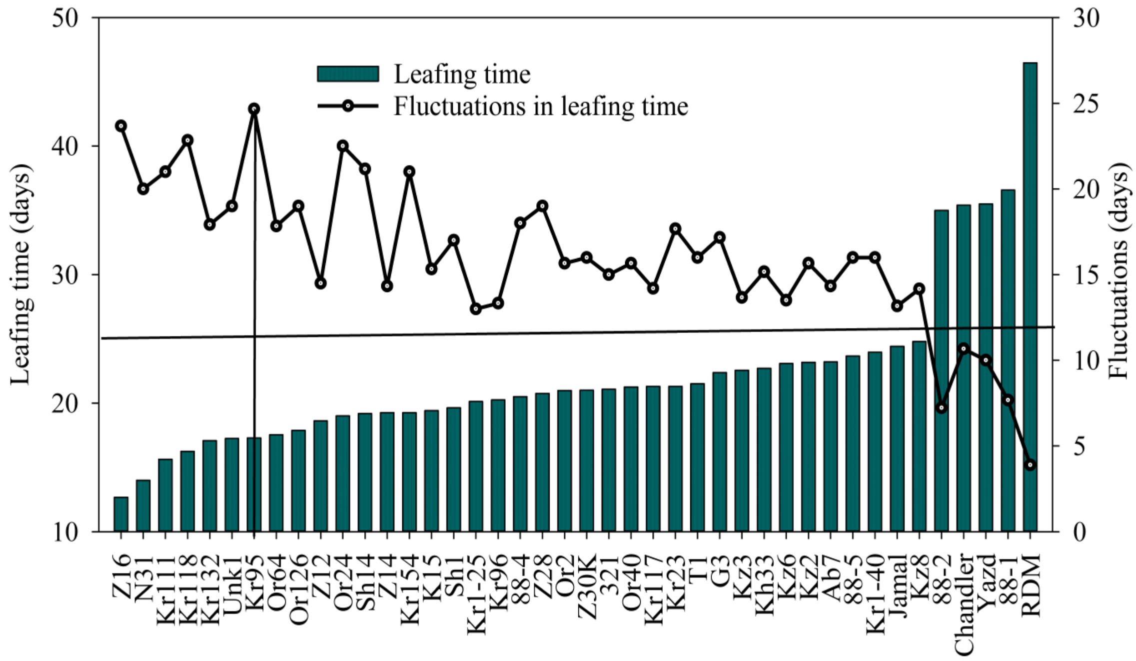

Fig. 4. Average of leafing time of walnut genotypes (days after the 1st March) and its variation during 2015-18 seasons

In addition to the genetic of genotypes, climatic conditions can led to differences in phenological attributes of walnut (Rezaei *et al*., 2018). Our results are consistent with the results of Arzani *et al.* (2008); Akca *et al.* (2015) and Mahmoodi *et al.* (2019) who reported the late leafing time in Iranian and Turkish genotypes were rare.

Late leafing cultivars have great importance due to avoiding late spring frost as observed in '88-1', '88-2' genotypes (Hassankhah *et al.*, 2017). In some of medium leafing genotypes such as 'Kz3' and 'G3', the long period of pistillate flowers receptivity, often due to the fruiting of most of lateral buds, is one of the characters contributing to compensate in occasions of the occurrence of late spring frost. These genotypes have long flowering period and could produce adequate number of female flowers after late spring frost. In the presence of pollen grains, therefore, they can produce fruits after late spring frost.

Significant genotypes × year interaction effect on leafing, first pistillate flowers receptivity and first pollen shedding showed that early leafing genotypes had much more variation in different seasons (Fig. 4). Therefore, the effect of season would be more important on these genotypes and make them more vulnerable to late spring frosts. The variation in leafing dates were more than 20 days in almost all early leafing genotypes. The highest variation observed in 'Kr95' and 'Z12' genotypes (25 and 24 days, respectively).

Ronde de Montignac, a very late leafing cultivar, had only variation of four days (April 13-17) for leafing date. Fallahi *et al*. (2014) reported that in late flowering nectarines, cultivars differences in bloom dates were not so great. They added that during warmer seasons, differences in bloom dates still existed between cultivars, but were less than in cooler seasons.

Study of regression analysis between March temperature and GDD with leafing date of early leafing genotypes, late leafing genotypes and Ronde de Montignac (very late leafing cultivar), indicated that there were significant differences among coefficients of regressions. Early leafing genotypes in comparison to late leafing ones had a higher regression coefficient (Fig. 5).

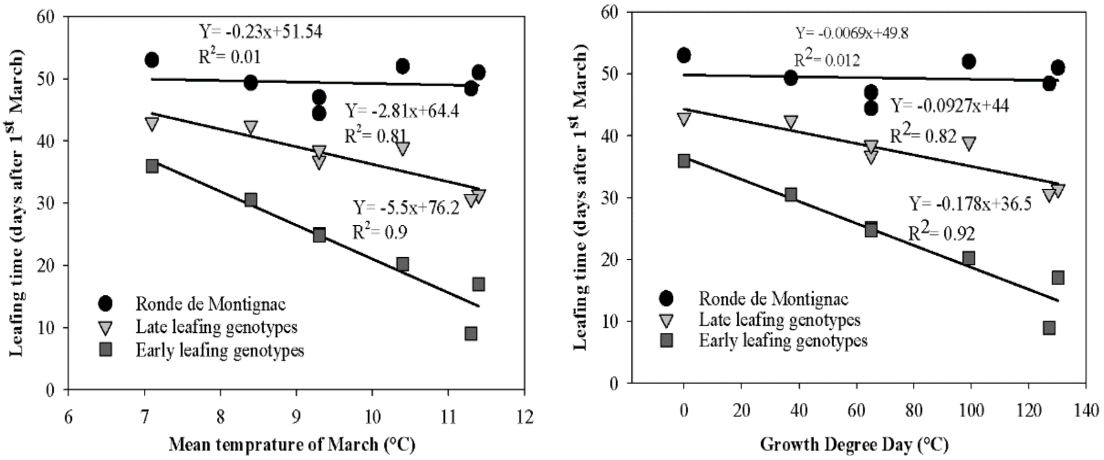

Fig. 5. Regression between mean temperatures and GDD of March with bud burst of early leafing and late leafing genotypes compared with cv. Ronde de Montignac during 2012-18.

It seems that the variation in phenological attributes of walnut (especially leafing time) mostly depends on genotype, which is due to differences in their GDD requirements. The differences between leafing time in early and late leafing genotypes, when the average temperature and consequently GDD was low, was less. Moreover, in seasons with higher temperatures in March, more variations were observed among genotypes (Fig. 4 and 5). Charrier *et al.* (2011) showed that growth rate in early and late leafing walnut genotypes were different under high and low temperatures which is in agreement with findings of this study. Hassankhah *et al.,* 2017 reported that early leafing cultivars are expected to have low heat requirements and therefore could show a quick response when temperature changed (5.5 days per degree of temperature) (Fig. 4 and5).

Late leafing genotypes including cv. Chandler, '88-1' and '88-2', had high heat requirements (Table 3). Theses genotypes needed higher heat accumulation to provide required GDD to demonstrate lower response to temperatures increase (2.8 days per degree increase in average temperature). Therefore, bud break in late leafing genotypes was more stable in different seasons. These results were in agreement with findings of Hassankhah *et al.* (2017) who showed that late leafing walnut genotypes and cultivars had higher heat requirements. They estimated 11832, 12180 and 12648 GDH, for 'Chandler ','88-1' and '88-2', respectively.

Bud break in walnut depends on chilling and heat requirements (Aslani Aslamarz *et al.*, 2009; Aslani Aslamarz *et al.,* 2010; Vahdati *et al.*, 2012). Therefore, cv. Ronde de Montignac, which was latest leafing cultivar

(Fig. 4), had the highest GDD (181 GDD). Other late leafing genotypes including 'Chandler', '88-1', '88-2' and 'Yazd' also needed 133, 132, 132 and 103 GDDs, respectively. The early leafing genotypes including 'Z16' and 'Kr111' required only 41 GDDs (Table 3 and Fig. 4). Cold months, November, December, January and February, were important in providing chilling requirements. In regions like Karaj with usually more than 1200 chilling hours available, chilling requirements of walnut genotypes is easily met (Aslani Aslamarz *et al.*, 2009; Vahdati *et al.*, 2012; Hassankhah *et al.*, 2017). In this situation, temperatures in March are important for starting the growth of walnut buds, catkin and pistillate flowers development.

Table 3. Growing degree day (GDD) for leafing time of walnut genotypes during 2015-18

Genotype	Season				Average	Genotype	Season				Average
	2015	2016	2017	2018	GDD		2015	2016	2017	2018	GDD
RDM	188	197	168	172	181	Or2	40	72	51	75	60
88-1	110	156	136	131	133	88-4	40	82	51	62	59
88-2	110	152	136	131	132	Or40	40	84	45	65	59
Chandler	110	149	136	131	132	Z14	40	64	43	87	59
Yazd	126	92	80	113	103	Sh1	40	69	51	67	57
Ab7	54	86	57	89	72	321	40	69	45	72	57
Kr1-40	64	85	57	79	71	Z12	40	64	43	79	57
Kz8	40	84	71	87	71	T1	45	69	46	65	56
Kz6	40	84	65	89	70	K15	40	69	45	67	55
Kz3	45	84	57	88	69	Or24	40	44	65	65	54
Kh33	45	84	65	79	68	Kr154	40	38	45	88	53
88-5	54	105	45	67	68	Or64	40	44	43	67	49
Kz2	45	91	57	72	66	Sh14	40	44	51	58	48
G3	45	72	57	89	66	Kr95	59	28	43	62	48
Jamal	54	83	57	67	65	Kr132	38	44	45	62	47
Kr23	54	69	57	79	65	Unk1	40	41	45	62	47
Z28	64	84	43	65	64	Kr118	40	58	45	40	46
Kr117	40	77	46	88	63	N31	38	45	42	58	46
Kr96	40	77	45	87	62	Or126	36	41	43	58	45
Kr1-25	40	72	45	88	61	Z16	44	45	40	43	41
Z30K	45	84	45	65	60	Kr111	40	19	43	62	41

RDM = Ronde de Montignac

Evaluation of pollen shedding and pistillate flower receptivity showed that among 42 genotypes, 21 were protogynous, 17 were protandrous and four were to some extent homogamous. However, some studies have reported that in walnut protandrous type were predominant (McGranahan and Leslie, 2006; Khadivi-Khub *et al.,* 2015; Rezaei *et al*., 2018).

The length of pollen shedding and pistillate flower receptivity periods showed to be more affected by environmental conditions (Mariana and Niculina, 2017). Based on the results of this study, the lowest pollen shedding and the shortest pistillate flower receptivity periods were six days in 2015, while the longest receptivity with eight days were observed in 2016. Among walnut genotypes, the longest pollen shedding period observed in genotypes 'KZ2', 'Kr117' with

11.5 days, and the shortest belonged to 'Yazd' with 5.5 days. Regarding the pistillate flowers receptivity period, 'G3' and 'Kz3'showed the longest duration with 15 and 14 days, respectively, and'Kz8' showed the shortest duration with 7.2 days (Fig. 6).

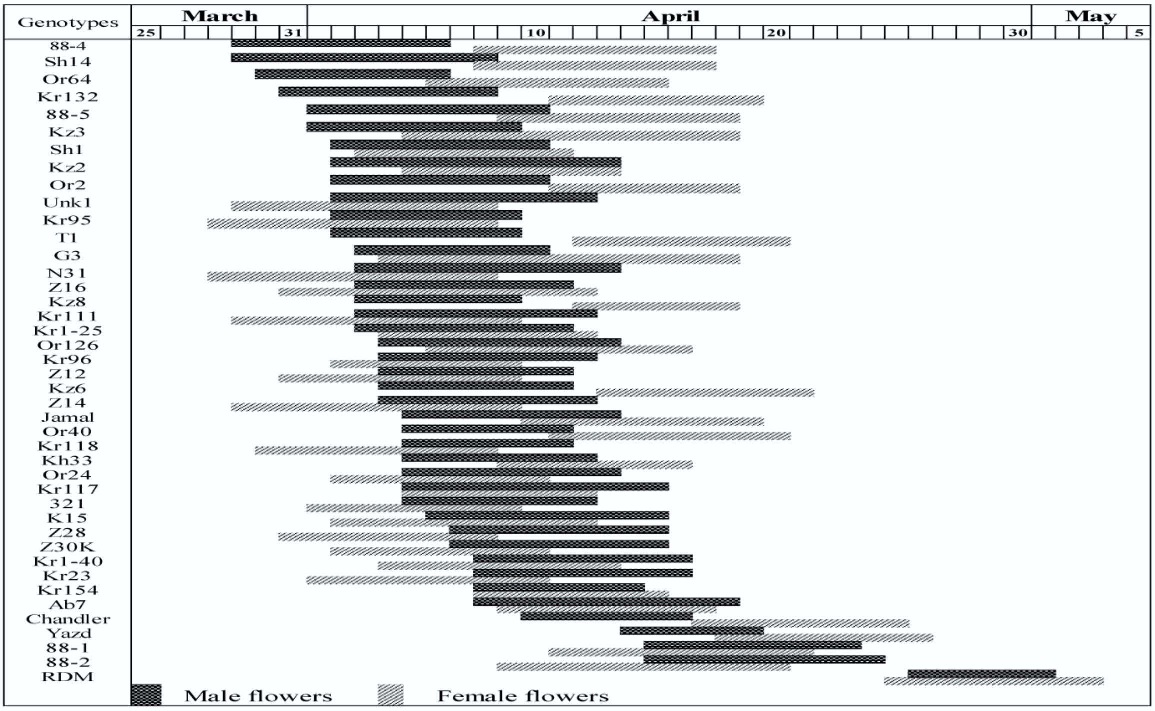

Fig. 6. Pollen shedding and pistillate flowers receptivity duration of walnut genotypes during 2015-18 seasons

Most of walnut genotypes had longer pistillate flower receptivity duration than pollen-shedding. This indicates the necessity of pollinizer tree(s) for sufficient pollination. Even in quite homogeneous cultivars where the male and female flowers usually appears simultaneously, it may happen that the length of pollen shedding period could be less than the pistillate flower receptivity period (for example in G3 and Kz3 genotypes), therefore, pollinizers are necessary.

Evaluation of ripening dates of walnut genotypes showed that there was not a significant difference in overall average in different seasons. Average ripening date in different seasons varied from August 24-25. The average temperature of growing period (March-September) during evaluated seasons ranged from 21.6 °C in 2016 to 22.4 °C in 2018. A significant correlation was found between average temperature of growth period and fruit ripening time (r = 0.82) and ripening period (r = 0.96). However, there was a strong correlation between ripening time and temperature. Nevertheless, because of slight variations in the mean temperature of the growth period over season, the effects of year on fruit ripening were not significant.

Fruit ripening time varied widely among different walnut genotypes, and it varied from August 15 to September 16. Asma (2012) reported that ripening time of 16 genotypes in Turkey was from the first week of September to the first week of October. Moreover, Rezaei *et al*., (2018) showed that time of fruit ripening of walnut genotypes in Malayer in Iran ranged from September 18 to October 2 These differences may be related to the cooler temperatures with an average annual temperature of 13.7 °C in Turkey and 13.7 °C in Malayer in Iran compared to Karaj in Iran with average annual temperature of 15.7 °C.

Among the evaluated walnut genotypes, cv. Chandler was the latest in ripening (September 16) (Fig. 7). Considering the ripening duration as the days after the end of pistillate flowers receptivity, genotype 'Z28' had the longest fruit growth period with about 150 days. The shortest fruit growth period belonged to 'Yazd' with 113 days (Fig. 7). There was also high significant correlation (r = 0.42**) between leafing date and ripening period, however, some early leafing genotypes such as 'Z28','321 ','Or64 ', 'Kr23 ' and 'Sh14' had a longer ripening period when compared with late ripening cultivars (e.g. cv. Chandler). Due to the early leafing habits, ripening time of these genotypes was 10 days earlier than cv. Chandler.

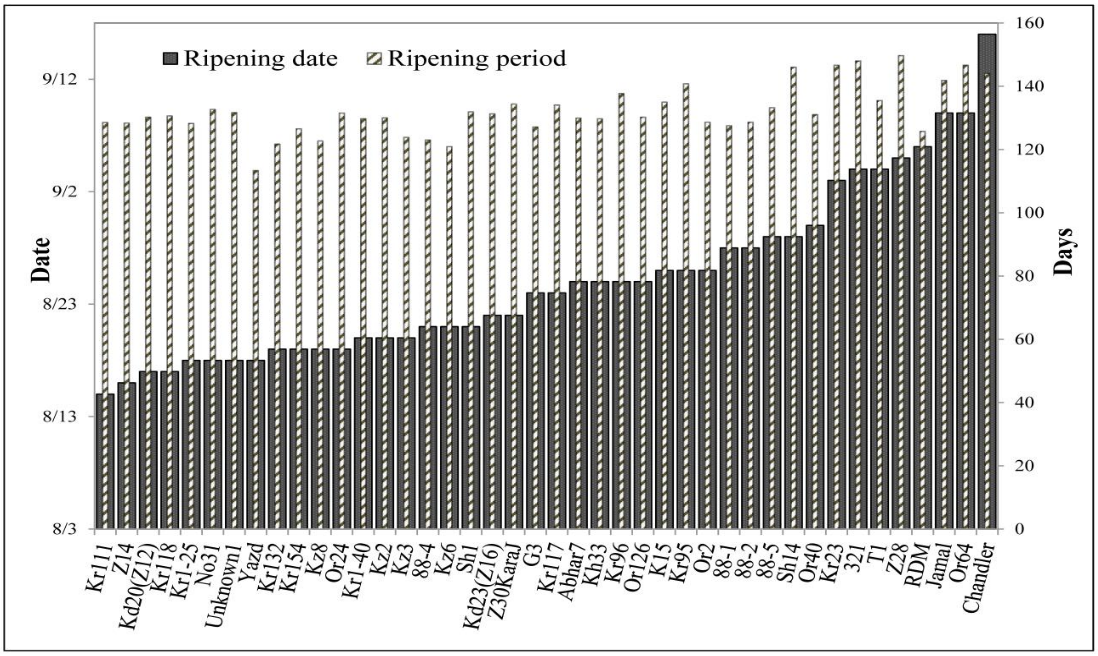

Fig. 7. The average ripening date and ripening period (day after the end of female flower receptivity) of walnut genotypes during 2015-18)

The results for cv. Ronde de Montignac with short ripening period (126 days) was similar, however, '88-1' and '88-2', were to some extent different. Despite of late leafing habit, these genotypes had a medium fruit ripening time (about 20 days earlier than cv. chandler). It could be due to their medium ripening period (128 and 129 days, respectively) and protogynous flowering habit.

The fruit ripening time of walnut is one of the most important traits in breeding programs (McGranahan and Leslie, 2006). It would be more important in cold regions where late ripening cultivars are planted, because there are concerns about coincidence of early autumn rainfalls or frost during ripening time, harvest and post-harvest operations. Low temperatures in early autumn are one of limiting factors walnut cultivation, especially at high altitudes, and early ripening cultivars are desirable in these area (McGranahan and Leslie, 2006). Adapted walnut cultivars, in addition to being late leafing to avoid the risk of late spring frost, should also be early to medium ripening in order to avoid the risk of early autumn frost (McGranahan and Leslie, 2006). Therefore, protogynous type could be more suitable, because of having more time for fruit growth and development (e.g. '88-1' and '88-2'). Very early ripening genotypes such as 'Kz3' and 'G3' seems to be more suitable in high-altitude where later leafing time and shorter growth period is desirable.

CONCLUSIONS

Based on the results of the present study, March temperatures had the highest effect on leafing dates, start of pollen shedding and pistillate flowers receptivity. In regions with adequate chilling requirements where chill units more than 1000-1200 hours usually are available and can meet the chilling requirements of walnut cultivars, temperature of March showed to be crucial for starting of the growth of walnut buds, catkin and pistillate flowers. A linear regression against March temperatures showed to estimate efficiently the bud burst, catkin and female flowers start time.

Early ripening is also one of the most important phenological characteristics in walnut breeding programs (McGranahan and Leslie, 2006). Since the effect of year was not significant on fruit ripening, it can be concluded that the evaluation of phenotypic performance is essential to select suitable cultivars. Selection of early ripening walnut cultivars is especially important in cold highlands areas where early fall frost may be a threat to walnut production. In these areas, late leafing with early –medium fruit ripening (about 20 days earlier than cv. Chandler) such as '88-1' and '88-2' genotypes can be grown. Moreover, in areas with shorter growth periods, medium leafing and early fruit ripening genotypes such as 'Kz3' and 'G3' can be grown.

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