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ORIGINAL ARTICLE

Top-working of Pecan Trees

Fereidoon Ajamgard

Department of Horticultural Research, Safiabad Agricultural Research and Education and Natural Resources Center, Agricultural Research, Education and Extension Organization (AREEO), Dezful, Iran

K E Y W O R D S

Carya illinoensis;
Cleft grafting;
Cultivar change;
Rejuvenation

A B S T R A C T

This research was conducted to determine the most appropriate grafting method for pecan trees in Dezful between 2019- 2022. Two experiments were carried out based on a completely randomized design in the form of a split-plot in three replications with grafting time at eight levels (from the second week of March to the first week of May) and three scion cultivars: 'GraKing'. 'Wichita' and 'Choctaw'. In the first experiment, fresh scions were used, and in the second experiment, the scions were prepared and kept at 4^{o}C for one month. The results of the first experiment showed that the grafting success in the first week of March was significantly higher than other dates at the level of 1%. The grafting was not successful in the second week of March and the first week of May. In the second week of April, 'Choctaw' had the highest rate of grafting success with 94%. The effect of grafting date and scion cultivar was significant at the 5% probability level in the growth, and 'Choctaw' had the highest height and diameter in the first and second year. In the second experiment, the results showed that the grafting success was significantly highest in the first week of April and the grafting was not successful in the second and third weeks of March. Finally, the middle of April was recommended as the best time for pecan trees top-working in Dezful condition.

Introduction

Pecan is the only genus of Juglandaceae with low chilling requrement which tolerates subtropical conditions well (Ajamgard *et al.,* 2017)**.** The origin of pecan is North and Central America, especially the coast of the Mississippi River and Texas, and the main production of this nut is in America and Mexico. About 147 thousand tons of pecans are produced by these two countries every year (Florkoski *et al.,* 1992; Prabhakar *et al.,* 2022). The pecan name comes from the Latin word Pecane, which means a nut that is broken by a stone, and in the last 100 years, it has had names such as Sweet pecan, Illinois nut, Faux hickory, and Pecan hickory (Arnold and Crocker, 1998). The high amount of unsaturated fatty acids (more than 75%.), especially oleic acid, found in pecan, is one of the unique features of this nut (Vazquez *et al.,* 1999). In America, pecan is known as the queen of nuts (Iqbal and Banday, 2013). There are more than 175 commercial varieties of pecan in American (Wood *et al.*, 1994).

In 1965, to study the compatibility of pecan cultivars, 18 plantlet of 12 cultivars were imported from California and planted at Safiabad Agricultural Research Center (Ajamgard *et al.,* 2013). Pecan trees have been planted in Golestan province, especially Gonbad city, in the last few decades. (Ghazaeian *et al.,* 2014).There are reports of pecan planting in Darab, Lahijan, Varamin and Noshahr. Pecan has high tolerance against heat and hot winds of subtropical regions. For example, in the summer of 2020, when

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the maximum temperature reached more than 50°C and most of the citrus orchards in the north of Khuzestan suffered from heat stress, no drying damage was observed in pecan (Ajamgard, 2022). Pecan is propagated by stem cuttings (Mc Eachern, 1973), layering (Wood, 1994), grafting (Ajamgard *et al.*, 2016) and tissue culture (Avila and Arreola., 2013). But the proper and usual method of its propagation is grafting of the selected varieties on the rootstocks (Vahdati et al., 2021).

Several environmental conditions influence grafting success in Juglandaceae, where grafting is difficult (Hartmann *et al.,* 2001). Adjustment of environmental factors, especially temperature, humidity and grafting time are effective in graft success (McEachern, 1992; Farsi *et al.*, 2016). Environmental conditions have a great impact on the formation of callus tissue during and after grafting. Among environmental conditions, temperature has the greatest effect on callus formation and grafting success (Hartmann *et al.,* 2001; Karadeniz, 2005; Farsi *et al.,* 2016). Fluctuation in temperature, especially during the annealing period, has a direct effect on callus development and grafting success, so that at 27°C,callus formation starts on the fifth day after grafting while at 22°C, it occurs six days after grafting. It is occured from grafting and at temperatures lower than 20°C, callus does not form in pecan (McEachern, 1992). Fluctuation in temperature, especially in the fourth week after grafting, has a direct effect on the development of callus and the success of grafting, so that at 27°C, the beginning of callus formation occurs on the fifth day after grafting, while at 22°C, callus formation occurs six days after grafting and at temperatures lower than 20°C, no callus is formed in pecan (McEachern, 1992; Farsi *et al.,* 2016). Temperature fluctuation also delays the grafting process. The most suitable temperature for walnut grafting is 26 to 27°C (Vahdati *et al.,* 2004; Rezaee and Vahdati, 2008; Sadeghpour *et al.*, 2016). The parenchymal cells forming the callus have very thin wall, therefore, callus tissues do not tolerate dryness and if they are exposed to dry air, they quickly lose their moisture and die (Rongting and Pinghai, 1993; Thapa *et al.*, 2021). As a result, calluses are formed and develop quickly only in the proper humidity (Dehghan *et al.,* 2010). When the humidity of the scion and grafting site is too low, the callus formation, connection of the rootstock callus and scion callus, formation of cambium and formation of vessels do not occur. To compare several pecan cultivars, including 'Wichita', crown grafting method in mid-spring was used (McEachern, 1992). In Kansas, for pecan grafting, the banana grafting method was used at the time of budbreak, and the inlay grafting method was suggested for larger trees (Reid, 2010).

Pecan is heterozygous and its propagation through seeds leads to the differentiation of vegetative and reproductive traits in the progeny, so grafting is the only practical and economic way to preserve the genetic characteristics of superior genotypes (Sparks, 2005).

There are two ways to increase the yield of pecan orchards. First, low-yielding and incompatible trees should be completely removed and replaced with high-yielding and compatible cultivars. Second, low-yielding trees should be grafted by scions of compatible and high-yielding cultivars (Wells, 2007).

Top-working is one of the best ways of changing cultivars (Rezaee *et al.,* 2014). With pecan top-working, the strong root system of the rootstock is used (Carroll, 2014). Considering the weak vegetative growth of pecan plantlets in the early years, it seems that the use of top-working is preferable. Deciding how to improve pecan orchards depends on the condition of the trees in the orchard. If the trees are healthy, strong and free from pests and diseases, especially termites, the crown of the tree is formed in two to three years after top-working, wich can been fruit in the fourth year. But if the pecan trees are weak, diseased and infected, it is better to remove all the trees from the orchard and re-plant planlets of high-yielding and compatible cultivars. On the other

hand, currently, the most important challenge for the increasing pecan orchards in Iran is the limited resources of scions from high-yielding cultivars. These scions are used to pecan propagation through grafting. With the supporting of the strong root system of rootstock, the branchs grow quickly after the trees top-working, and in a short period of time, many one-year branches are produced, which become an important source for preparing scions. In this research, we proposed a scientific and practical method with high success for the top-working of large pecan trees**.**

Materials and Methods

This project was implemented in Safiabad Agricultural and Natural Resources Research and Education Center (Dezful) for 2021-2022 in order to determine the best time for top-working pecan trees using scions of three cultivars.

Meteorological specifications of Safiabad Agricultural Research Center, Dezful:

- Latitude: longitude **-** 32.38° N, 48.42°E
-Above sea level: 143 m
-Average annual temperature: 23.9°C
- Maximum temperature: 51.8°C
- Minimum temperature: -2.2°C
-Annual evaporation rate: 2800 mm
- Annual rainfall: 320 mm

This research was conducted based on a completely randomized design in the form of a split-plot experiment with grafting date as the main factor at eight levels (from the second week of March to the first week of May with a one week interval) and the cultivar as the second factor in three levels 'Graking', 'Wichita' and 'Choctaw' with three replications. For this purpose, two experiments were performed. In the first experiment, the scions were used for grafting immediately after preparation from the mother trees. One month before the second grafting, the scions were prepared and kept at 4°C for one month. Each tree with four scions was considered as an experimental unit.

Plant materials

In this research, 144 pecan trees with an age of 24 years were selected (Figure 1). The maintenance conditions of trees were the same. The trunk diameter of the trees was between 25 and 30 cm. The scions were prepared from one-year branches of ‘Graking’, ‘Wichita’ and ‘Choctaw’

Fig. 1. Perennial pecan trees that were top-worked.

Top-working method

Preparation of scion

The scions were prepared from healthy one-year branches without any signs of sunburn, pests and diseases. The steps of pecan top-working are shown in Fig. 2 (a-f)**.**

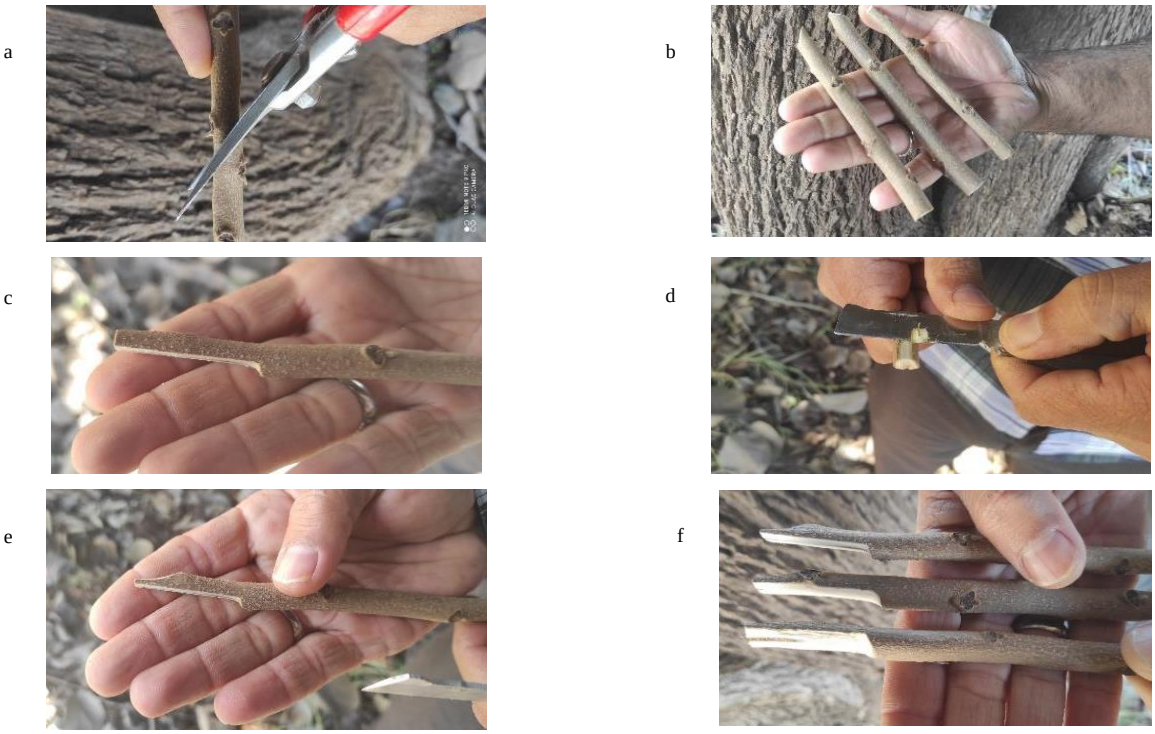

Fig. 2. Procedures for preparing scions from one-year-old pecan branches (a-f).

The trunk of a pecan tree was cut from a height of one meter. The cutting of the tree trunk was done without any signs of damage to the trunk (Fig. 3a).

The stages of pecan trees top-working

After smoothing the cross-section of the tree trunk, a vertical cut of 8 to 10 cm length was made on the bark of the trunk with a grafting knife (Fig. 3b) and the scion was placed under the bark (Fig. 3c). According to the diameter of the trunk, 3 to 4 scions were grafted on each trunk. The scions were fasten on the trunk by wire (Fig. 3d) and covered with adhesive tape around the grafting site (Fig. 3e). Wet cocopeat was used to maintain humidity (Fig. 3f-3h).

Assessed traits

The evaluated traits were the percentage of grafting success, the height and diameter of the scions at the end of the growing season of the first and the second year. Data were analyzed with SAS 9.4 statistical software and the averages were compared using Duncan's multi-range test ($P \leq 0.05$).

Fig. 3. Steps of pecan trees top-working

Results

Four weeks after grafting in both experiments, the percentage of grafting success in different treatments was evaluated (Fig. 4).

Fig. 4. Situation of the scions four weeks after pecan tree top-working

First experiment

Table 1 shows the analysis of variance of grafting success, length and diameter growth of scions in the first and second years. The results showed that grafting time at 1% level had a significant effect on the grafting success, length and diameter growth of scions. Also, cultivar had an effect on grafting success at the5% probability level and on the annual growth of scions at the 1% probability level.

Table 1. The analysis of variance of pecan scion growth in the first experiment (fresh scion).

S.O.V	DF	Sum of squares				
		Grafting survival (%)	Scion growth in the first year (cm)	Scion growth in the second year (cm)	Scion diameter in the first year (mm)	Scion diameter in the second year (mm)
Grafting date	7	81063**	444376**	799800.1**	9860.4**	17529.3**
Error	14	260	4920.7	11953.1	450.4	447.3
Cultivar of scion	2	233.5*	38033.5**	82869.7**	1156.1**	1563.4**
Grafting date × Cultivar	14	1142.4**	13849.8**	35406.8**	537.7**	788.6*
Error	32	836	2440.7	22772.9	330.2	479.3
Total	71	83535.8	503621.3	952802.6	12334.9	20807.9
Cv		13.44%	9.09%	14.57%	15.58%	13.95%

ns, * and ** represent nonsignificant, significant at P = 0.05 and 0.01, respectively

The results showed that the success of grafting of pecan trees in late March and early April, regardless of the type of scion cultivar, was significantly higher than other dates at the 1% level. The grafting of pecan trees was not successful in the first half of March and the end of April. Fig. 5 shows the percentage of grafting success at different dates.

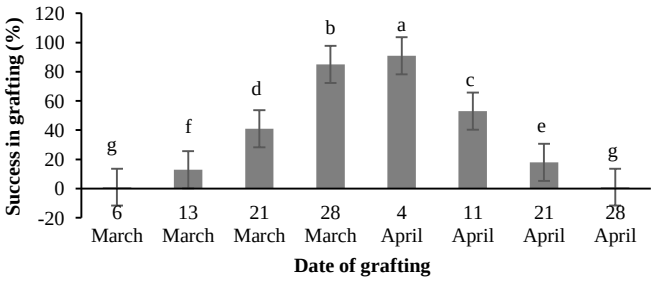

Fig. 5. The effect of grafting time on the success rate of grafting in the first test (fresh scion) in pecan top-working. Means of columns followed by the same letter are not significantly different according to Duncan's multiple range test (P≤0.05)

Fig. 6 shows the effect of grafting date and scion cultivar on the success of grafting in the first experiment (fresh scion). The results showed that the 'Choctaw' scion has the highest grafting success in the first week of April with 94%. Difference in grafting success between other cultivars was not significant at this date.

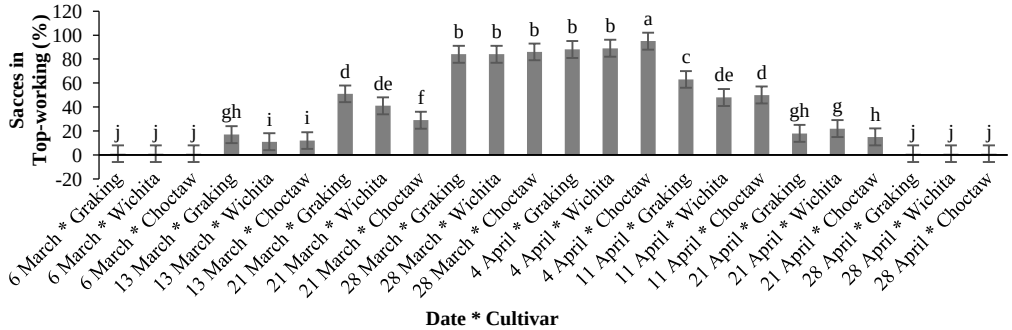

Fig. 6. Comparison of the interaction effect of grafting time and cultivar on grafting success rate in the first experiment (fresh scion) in pecan top-working. According to Duncan's multiple range test, the means of columns followed by the same letter are not significantly different (P≤0.05)

The results showed that the effect of grafting date and scion cultivar on the height of the grafted branch in the first experiment (fresh scion) in the first (Fig. 7a) and second year (Fig. 7b) was significant at the 5% probability level, and the 'Choctaw' scion had the highest growth in the first and second year (Fig. 8).

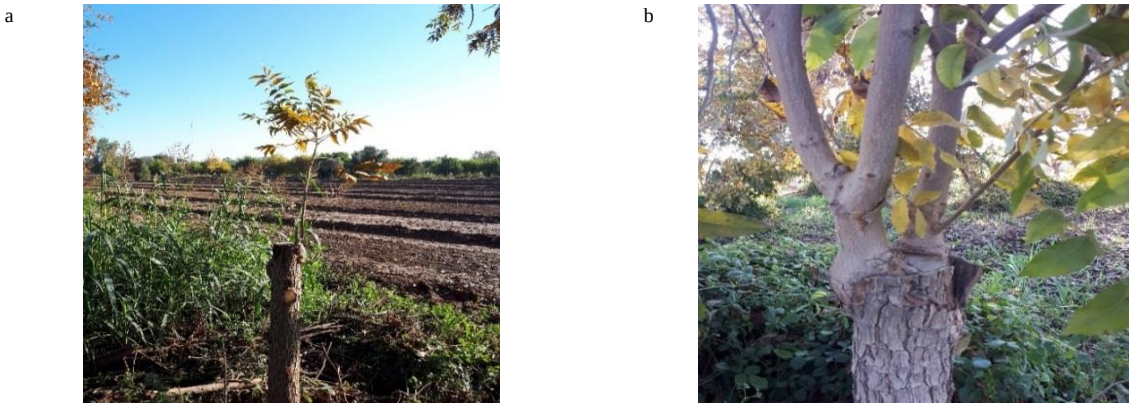

Fig. 7. The growth of scions in the first year (a) and second year (b) after pecan top-working

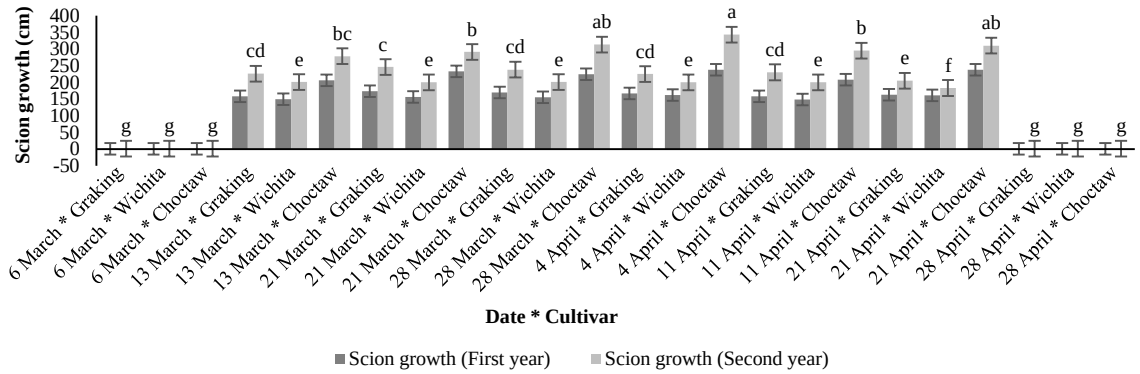

Fig. 8. Comparison of the average effect of grafting time and variety on scion height in the first experiment (fresh scion) after pecan top-working. Means of columns followed by the same letter are not significantly different according to Duncan's multiple range test (P≤0.05)

The results showed that the effect of grafting date and scion cultivar on the diameter of the grafted branch in the first experiment (fresh scion) in the first year and the second year was significant at the 5% probability level, and the 'Choctaw' scion had the highest diameter with 50mm in the first and second year (Fig. 9).

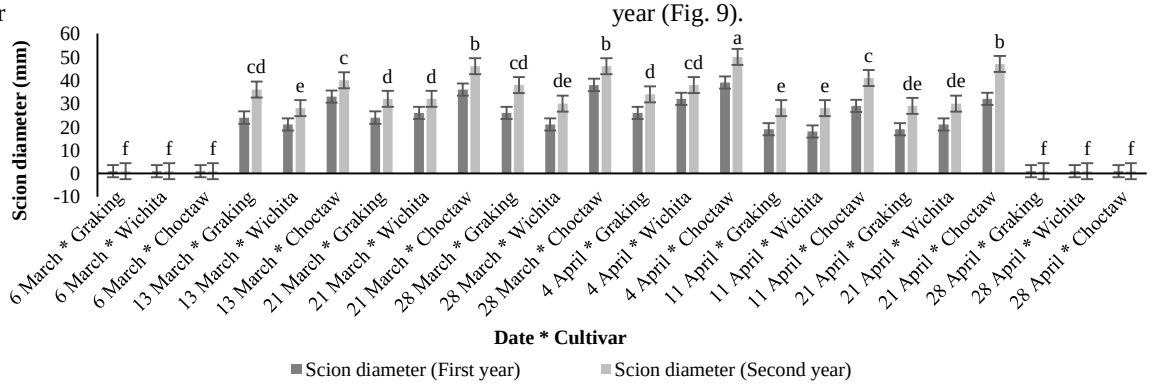

Fig. 9. Comparison of the average effect of grafting time and variety on scion diameter in the first experiment (fresh scion) after pecan top-working. Means of columns followed by the same letter are not significantly different according to Duncan's multiple range test (P≤0.05)

Second experiment

Table 2 shows the analysis of variance of grafting success, length and diameter growth of the scions that were kept in the refrigerator for one month in the first and second years. The results showed that grafting time at 1% level had a significant effect on grafting success, growth of scions length and diameter. Also, cultivar had an effect on grafting success at the 5% probability level and on the annual growth of scions at the 1% probability level.

The results showed that the success of grafting pecan trees using scions kept in the refrigerator for one month in the first week of April, regardless of the cultivar, was significantly higher than other dates at the level of 1%. The grafting was not successful in the first and second week of March. Fig.10 shows the comparison of the average grafting success at different dates.

Table 2. The analysis of variance of pecan scion growth in the second experiment (using stored scion at 4 c for one month)

S.O.V	DF	Sum of squares				
		Grafting survival (%)	Scion growth in the first year (cm)	Scion growth in the second year (cm)	Scion diameter in the first year (mm)	Scion diameter in the second year (mm)
Grafting date	7	22527.7**	319398.4**	482713.7**	5148.4**	11413.1**
Error	14	1096.2	14509.6	18724.9	576.9	826.22
Cultivar of scion	2	164.7**	20313.4**	29306.8**	246.4**	539.1**
Grafting date × Cultivar	14	992.2**	11059.5	17353.4*	217.2*	485.8
Error	32	310.44	12590.4	19155.8	292.4	464.4
Total	71	25091.3	377871.2	567254.6	6481.3	13728.6
Cv		13.43%	17.29%	17.34%	19.75%	17.1%

ns, * and ** represent nonsignificant, significant at P = 0.05 and 0.01, respectively

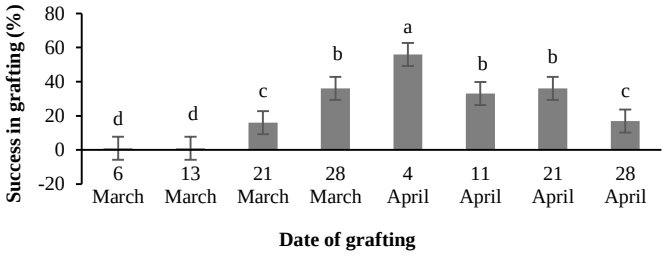

Fig. 10. The effect of grafting time on the success rate of grafting in the second test (The scion kept in the refrigerator for one month) in pecan top-working. According to Duncan's multiple range tests, the means of columns followed by the same letter are not significantly different according to Duncan's multiple range test (P≤0.05)

Fig. 11 shows the effect of grafting date and scion cultivar on the success of grafting in the second experiment (scion kept in the refrigerator for one month). The results showed that the 'Wichita' has the highest grafting success in the second week of April with 60%.

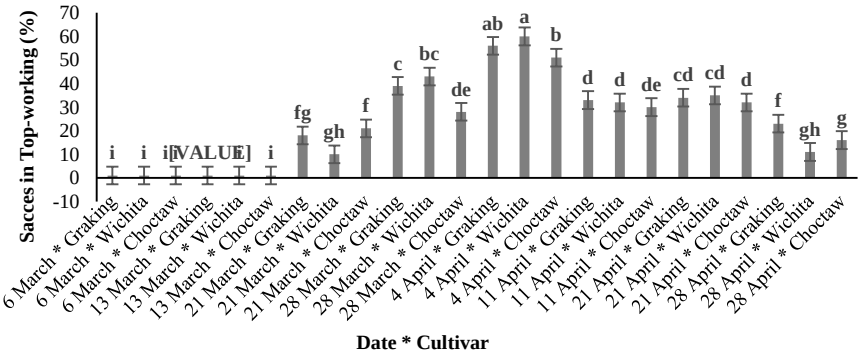

Fig. 11. Comparison of the average interaction effect of grafting time and cultivar on grafting success rate in the second experiment (the scion kept in the refrigerator for one month) in pecan top-working. According to Duncan's multiple range tests, the mean of columns followed by the same letter are not significantly different according to Duncan's multiple range test (P≤0.05).

The results showed that the effect of grafting date and scion cultivar on grafted branch height in the second experiment (scion stored in the refrigerator for one month) was not significant in the first and second year. At the end of the second year, the scion of 'Choctaw' grew to a height of 250 cm (Fig. 12).

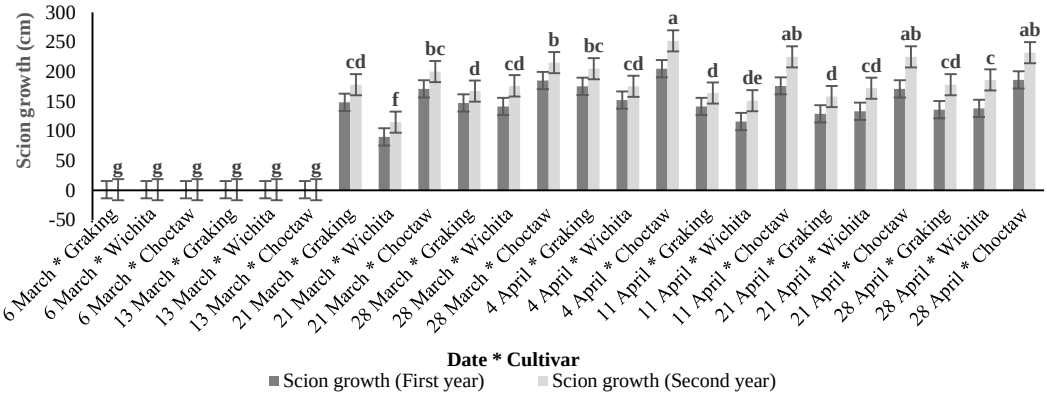

Fig. 12. Comparison of the average effect of grafting time and variety on scion height in the second experiment (The scion kept in the refrigerator for one month) after pecan top-working. According to Duncan's multiple range test, the means of columns followed by the same letter are not significantly different (P≤0.05).

The results showed that the effect of grafting date and scion cultivar on grafted branch diameter in the second experiment (scion stored in the refrigerator for one month) was not significant in the first and second year. At the end of the second year, the diameter of the 'Choctaw' grew to 37mm (Fig. 13).

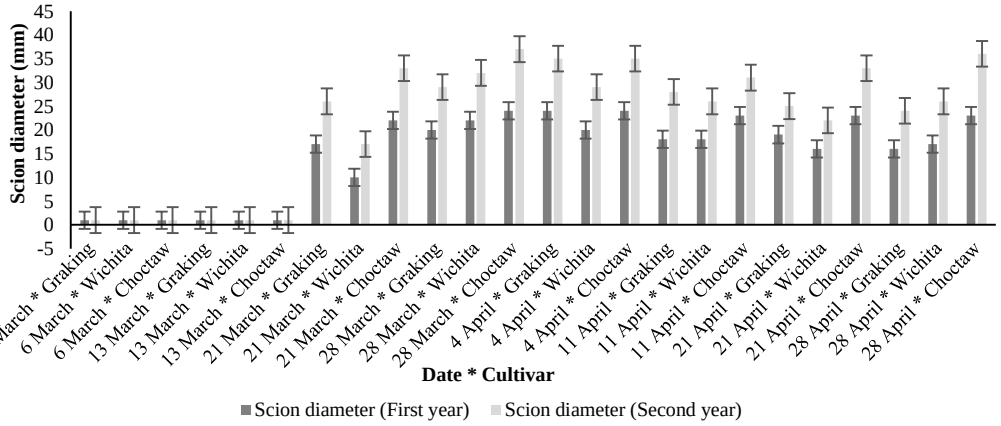

Fig. 13. Comparison of the average effect of grafting time and variety on scion diameter in the second experiment (The scion kept in the refrigerator for one month) after pecan top-working. According to Duncan's multiple range tests, the means of columns followed by the same letter are not significantly different (P≤0.05).

Discussion

There are two main reasons for top-working a pecan tree. One is to install a better cultivar onto an old stock. A better cultivar may bear nuts earlier, produce more nuts, have better quality nuts, and have a natural resistance against insects and diseases. The second is to ensure clonal genetic identity. Having a clone grafted variety can greatly assist with orchard management (Casales *et al.*, 2018). Top-working is the only practical way to improve these trees, and using grafting methods is a turning point in the development of commercial pecan orchards in the world (Zhang *et al.*, 2015). The use of a very strong root system of trees in the pecan top-working accelerates the growth of the scion and creates a crown of a high-yielding cultivar in a short time (Sparks, 2005., Yates and Sparks, 1992).

The top-working of pecan trees as the only nuts of subtropical regions of Iran is important from two aspects. First, seeds of pecans have been cultivated in different regions for many years, and currently these

trees do not have a specific and high-yielding cultivar. The second point about the importance of pecan trees top-working is the production of scions needed to establish pecan orchards in Iran. The growth of 2 to 3 meters of scion in the second year after grafting is a very valuable source of pecan scion. This feature is especially important in the early years of the development of pecan orchards, when the resources of pecan scions in the country are very limited.

This research showed that mid-April is the best time for pecan top-working in Dezful, which was consistent with the results of Sharma in India (Sharma *et al.,* 2022). They showed that with the 'Hartley' scion, the success of grafting was 83% in mid-April. Wells in America reported that the highest success of Pecan grafting was in the fourth week of April (Wells, 2007). Carroll reported that April 12-19 is the best time for pecan grafting by inlay grafting method and 'Desirable' scion (Carrol, 2014). On the other hand, the most suitable date for top-working pecan trees in Kashmir was reported in the second week of March. In their report, the success of Pecan grafting was 69% (Mehta *et al.,* 2018). Also, early March is recommended for ‘Mahan’ pecan trees. As well as, Stafne also reported that mid- to late April is generally a good time to graft pecans. Once hot weather sets in, grafting success will be diminished. Removal of old top can be done when the tree is to be grafted in April or early May (Rehman *et al*., 2000; Joolka *et al.,* 2001). When the new leaves start to open, the tree signals to you that it is the best time to start top-working (Thomas and Prindle, 2014).

In the conditions of Dezful, when the air temperature rises from the mid-spring, attention should be paid to the state of establishment and subsequent growth of the scions. Although the callus was formed on the dates after April 15, but due to a sharp increase in temperature, the stages of connecting the rootstock and scion was not completed, and after removing the coco-peat cover, the scion dried. The results of this research showed that the main success factor in the pecan top-working was the time of grafting. Also, the results showed that the grafting success was different with the scions of different pecan cultivars, which was consistent with Mc-Crown's opinions (Mc-Crown, 2007).

The most common graft used in top-working Pecan trees is the inlay bark grafting, which has been successfully used when other systems have failed due to heat, drought and wind (McEachern *et al.,* 1992). Generally, Pecan trees with a diameter between 7.5 and 30 cm and a height of 1.40 m above the ground are top-worked (Stafne, 2022).

Conclusions

Finally, the middle of April was recommended as the best time for pecan trees top-working in Dezful condition.

Acknowledgements

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Conflict of interests

The author reports that there are no competing interests to declare.

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