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Pruning and girdling influence alternative bearing of 'Kinnow' mandarin (*Citrus reticulate* Blanco)

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ABSTRACT

Purpose: This study was undertaken to investigate the effects of pruning and girdling on yield, fruit size and quality of 'Kinnow' mandarin (*Citrus reticulate* Blanco) trees during two seasons. **Research method:** The treatments included: control (unpruned and ungirdled trees), light pruning (removal 10% of 15-20 cm branches), intense pruning (removal 20% of 15-20 cm branches), girdling (removal 5 mm trunk bark), light pruning + girdling, and intense pruning + girdling. The treatments were applied in on-years (2016 and 2018) and traits were measured in following season. **Findings:** Light pruning increased yield and fruit number by 170.4% and 191.5%, respectively, while fruit weight and volume slightly decreased by 7.2% and 12.4%%, respectively, compared to control. Fruit dimensions and, TSS and TA of fruit juice were not affected by treatments. However, TSS/TA ratio was significantly declined in both pruning treatments. In addition, vitamin C content of fruits decreased in pruned trees and light pruned + girdled trees compare to control. The yield was positively correlated with fruit number and negatively with fruit weight, fruit volume and vitamin C content. **Limitations:** Despite these findings, more research is needed to identify mechanisms of pruning and girdling on alternative bearing in citrus. **Originality/Value:** These results suggested that pruning alone or plus girdling of 'Kinnow' mandarin trees reduce competition for nutrients and induce accumulation of carbohydrates in branches, which enhanced yield of the next season.

INTRODUCTION

Citrus is one of the world's major fruit crops with global availability and popularity contributing to human diets (Liu et al., 2012). Iran is one of the largest citrus producer in the world (Miri, 2013), as its production to 4.07 million ton in 2019 (FAO, 2019). The main varieties of *Citrus* grown in Iran are 'Navel' and 'Valencia' oranges, 'Page' and 'Kinnow' mandarin and 'Orlando' tangelo (Ebrahimi, 2002). 'Kinnow' mandarin is a hybrid of 'King' (*C. nobilis*) × 'Willow Leaf' (*C.* × *deliciosa*) that has been distributed widely in several countries. The 'Kinnow' fruits are medium in size, seedy, very juicy, flavor-rich, aromatic and distinctive. This cultivar is also high productive and has strong tendency for alternate bearing (Miri, 2013; Miri et al., 2018).

Alternate bearing, also known as biennial or uneven bearing, is a major problem in citrus fruit production all over the world especially within the mandarin and their hybrids. Fruit trees tend to produce a heavy crop in one year (on-year), followed by a light crop in the next year (off-year) (Mirsoleimani et al., 2018). In citrus, various internal and external factors affect alternate bearing, including low C/N ratio, unbalanced hormones, root starvation, abiotic stresses, and soil nutrient availability (Abobatta, 2019). Several techniques such as girdling, reduction in crop load by thinning or pruning and early fruit harvesting can enhance carbohydrates and starch accumulation leading to flower formation in the next growth season (Hekmati & Miri, 2012; Mirsoleimani et al., 2018). On the other hand, gibberellin-like compounds produced in developing fruits of citrus can directly or indirectly reduce flowering in the spring following the on-year in some cultivars (Ladaniya, 2008; Shalom et al., 2012). Girdling involves the removal of a strip of bark from the circumference of the trunk or scaffold branches (Agustí & Primo-Millo, 2020). It enhances fruit set in Citrus through the accumulation of photoassimilates in the canopy as a result of the interruption of the downward transport of soluble sugars (Miri, 2013; Rivas et al., 2006). In addition, correct pruning by removing excess shoots and fruits can improve yield, fruit size and fruit quality, and overcome alternate bearing (Hekmati & Miri, 2012).

MATERIALS AND METHODS

The experiment was carried out in the research citrus orchard of Southern Kerman Agricultural and Natural Resources Research and Education Center, AREEO, Jiroft, Iran. Kinnow mandarin trees (*Citrus reticulate* Blanco) were about 12-year-old budded on sour orange (*Citrus aurantium* L.) rootstock and planted in clay-loam soil. The experimental trees were subjected to the recommended horticultural practices adopted in the commercial citrus orchards in respect of irrigation, fertilization, and weed and pest control. At the end of winter 2015, the dead and infected branches of the mandarin trees were removed to improve the growth conditions and fruit quality. The experiment involved six treatments including 1) control (unpruned and ungirdled trees), 2) light pruning (removal about 10% of 15-20 cm branches), 3) intense pruning (removal about 20% of 15-20 cm branches), 4) girdling, 5) light pruning plus girdling, 6) intense pruning plus girdling.

Pruning of branches was performed in late April after anthesis. Girdling was also carried out in mid-December at 30 cm above the grafting point by removing about a 5 mm width of the bark around the trunk using a girdling knife without injuring the wood. The treatments were applied in 2016 and 2018 (on-years) and physical properties and chemical constituents of fruits were measured in 2017 and 2019 (off-years).

Fruits were picked from each replicate in late January to determine the yield and fruit characteristics as follows: fruit number, fruit weight, fruit dimensions (height and diameter),

fruit volume as well as TSS, TA, TSS/TA ratio and vitamin C content of fruit juice. The total soluble solids (TSS) were determined in using a hand refractometer. Titratable acidity (TA) was measured as citric acid by titration against 0.1 N sodium hydroxide solutions and the total acidity percentage was estimated; the TSS/TA ratio (taste index) was calculated. Vitamin C (ascorbic acid) content was determined by titration with potassium iodate in the presence of potassium iodide (Kiani Majd et al., 2021).

The experiment was arranged in a complete randomized block design with three replicates, each consisted of two trees. The obtained data were statistically analyzed using SPSS software ver. 23. The individual comparisons between the obtained values were carried out using Duncan's Multiple Range Test ($P \leq 0.01$). Pearson correlation coefficients were calculated to determine the relationship between the traits.

RESULTS

Table 1 illustrates the effects of the pruning and girdling treatments on physical properties and chemical constituents of 'Kinnow' mandarin fruits. Yield and fruit number improved significantly by pruning alone or with girdling ($P \leq 0.01$). However, pruning and girdling had no significant effects on fruit dimensions. Accordingly, light pruned trees had the highest yield (35.7 kg) and fruit number (354.8) per tree (2.7 and 2.9-fold compare with control), followed by light pruned + girdled trees. The control trees were found to have the heaviest (108.4 g) and largest (175.5 cm^3) fruits, whereas those that had been light pruned had the lightest (100.6 g) and smallest (153.7 cm^3) fruits.

Pruning and girdling did not affect the TSS and TA of fruits, while TSS/TA ratio decreased significantly with both pruning methods ($P \leq 0.01$), as the highest TSS/TA was found in light pruned + girdled (9.4) and control (9.3) trees followed by intense pruned + girdled (8.8) and girdled (8.2) trees. In addition, vitamin C content of fruits declined in pruned (48.5 and 50.2 mg/100 ml fruit juice in light and intense pruned trees, respectively) and light pruned + girdled trees (50.7 mg/100 ml fruit juice) compare with control (53.2 mg/100 ml fruit juice).

Yield presented a very high positive correlation with fruit number ($r = 1.00$; $P \leq 0.01$) and negative correlation with fruit weight, fruit volume and vitamin C content ($r = -0.82$, -0.85 and -0.77, respectively; $P \leq 0.01$) (Table 2). There was a positive correlation between fruit weight with TSS/TA ratio and vitamin C content ($r = 0.70$ and 0.93, respectively; $P \leq 0.01$). Moreover, fruit dimensions (fruit height and diameter) with fruit quality parameters (TSS, TA, TSS/TA ratio and vitamin C content) were positively correlated.

Table 1. Effect of pruning and girdling on physical properties and chemical constituents of 'Kinnow' mandarin fruits (mean values for 2017 and 2019)

Treatment	Yield (kg/tree)	Fruit number	Fruit weight (g)	Fruit height (cm)	Fruit diameter (cm)	Fruit volume (cm^3)	TSS (%)	TA (%)	TSS/TA	Vit C (mg/100 ml fruit juice)
Control	13.2 e	121.7 e	108.4 a	6.7	7.2	175.5 a	8.4	0.91	9.3 a	53.2 a
LP	35.7 a	354.8 a	100.6 e	6.4	6.9	153.7 e	8.1	1.10	7.4 bc	48.5 d
IP	22.4 c	218.5 c	102.5 d	6.4	7.0	157.5 d	8.0	1.20	6.8 c	50.2 cd
G	14.2 e	133.9 e	106.0 b	6.6	7.1	168.0 b	8.2	1.05	8.2 abc	51.5 abc
LP+G	26.2 b	251.4 b	104.2 cd	6.5	6.9	157.5 d	8.4	0.95	9.4 a	50.7 bc
IP+G	19.2 d	183.7 d	104.5 bc	6.5	7.0	160.9 c	8.3	0.97	8.8 ab	52.2 ab
Sig.	**	**	**	ns	ns	**	ns	ns	**	**

TSS: total soluble solid, TA: titratable acidity, Vit C: vitamin C, LP: light pruning, IP: intense pruning, G: girdling, Sig: significance: **, ns: non-significant and significant at $P \leq 0.01$, respectively.

Table 2. Correlation coefficients among physical properties and chemical constituents of 'Kinnow' mandarin fruits

Trait	Yield	Fruit number	Fruit weight	Fruit height	Fruit diameter	Fruit volume	TSS	TA	TSS/TA
Fruit number	1.00**								
Fruit weight	-0.82**	-0.83**							
Fruit height	-0.02ns	-0.10ns	0.41ns						
Fruit diameter	-0.03ns	-0.11ns	0.40ns	1.00**					
Fruit volume	-0.85**	-0.87**	0.93**	0.23ns	0.23ns				
TSS	0.18ns	-0.07ns	0.41ns	1.00**	0.98**	0.20ns			
TA	0.14ns	0.06ns	0.19ns	0.96**	0.97**	0.02ns	0.94**		
TSS/TA	-0.26ns	-0.33ns	0.70**	0.68**	0.63**	0.46ns	0.75**	-0.50*	
Vit C	-0.77**	-0.81**	0.93**	0.54*	0.54*	0.81**	0.55*	0.35ns	0.75**

TSS: total soluble solid, TA: titratable acidity, Vit C: vitamin C, LP: light pruning, IP: intense pruning, G: girdling, Sig: significance ns, *, ** non-significant and significant at P ≤0.05 and 0.01, respectively.

DISCUSSION

Pruning and girdling are crucial cultural practice in citrus production, which provides sustainability for fruit production in the long-term (Hekmati & Miri, 2012; Miri, 2013). According to our results, pruning alone or with girdling significantly enhanced fruit number and reduced fruit weight. Growing fruits compete for nutrients and carbohydrates. Thus, heavy bearing trees produce fruit of smaller size. The strong negative correlation between fruit weight and volume with yield and fruit number also confirms this hypothesis that fruit size is inversely related to the number of fruits on the tree (Ladaniya, 2008). These results are in line with those reported by Ibrahim et al. (2016) on Washington navel orange, who found that branch girdling reduced fruit weight and size. They suggested that decreasing the leaf/fruit ratio due to the increment in fruit number by girdling might reduce the physical properties of the fruits. On the contrary, Yilmaz et al. (2018) found that the fruits of Robinson mandarin shifted toward larger sizes when the trees were girdled.

The floral induction period in citrus starts in mid-November and lasts until approximately the end of December to mid-January (Shalom et al., 2012). Positive correlations have been shown between carbohydrates accumulation and flowering, which have led researchers to assume that the levels of carbohydrates may be a limiting factor in flower bud formation in citrus (Mirsoleimani et al., 2018). Girdling interrupts the photosynthates movement through the phloem, which increases soluble carbohydrates (sugar and starch) in the upper parts of the girdling, is resulting in increased flowering (Gawankar et al., 2019). Furthermore, girdling affects the expression of genes related to starch accumulation (Rivas et al., 2006). Ibrahim et al. (2016) suggested that the accumulation of carbohydrates in girdled branches and limbs of Washington navel orange trees enhanced fruit set and fruit yield after girdling. Quantitatively the response depended on the date of girdling, the maximum occurring in those trees girdled at the end of July. Girdling of 'Tahiti' acid lime trees at 108 and 78 days before flowering onset increased fruit set by 229 and 256%, respectively, compared to control (ungirdled trees) (Pereira et al., 2014). Similarly, girdling branches and limbs of 'Washington navel' orange trees increased number of flowers, fruit set and number of harvested fruits/branch relative to ungirdled trees (Ibrahim et al., 2016). Ghosh and Bera (2014) also indicated that fruit production of sweet orange 'Mosambi' improved with regular pruning. Iglesias et al. (2003) concluded that fruit set in citrus is highly dependent on carbohydrate availability. The 'Kinnow' mandarin crop is mid-season in maturity and harvested in January-February (Miri et al., 2017). Since the fruits were the most powerful sink for carbohydrates and prevented the accumulation of reserves in 'Kinnow' mandarin leaves (Mirsoleimani et al., 2018), heavy crop load depletes sugar and mineral reserves in the on-year. Mirsoleimani et al. (2018) also found that the endogenous levels of total non-structural carbohydrates and soluble sugars in leaves and starch content of stems are influenced by alternate bearing of 'Kinnow' mandarin

trees. On the other hand, one of the well-known flowering inhibitors is gibberellic acid, which is produced by developing fruits and can reduce flower formation (Pereira et al., 2014). Pruning in the spring can be used as a thinning method to reduce flower number (Verreynne, 2009). Therefore, pruning by removing bearing surface and management of crop load can stimulate the induction of flower bud formation, through reduction of gibberellin-like substances produced in seeds and completion for carbon reserves; ultimately increase the yield of the next season (Ebneali et al., 2013).

Our results mentioned that lightly pruned trees have the highest yield and number of fruits. Proper pruning is critical for maintaining the fruiting potential of citrus trees. In contrast, severe pruning stimulates vigorous new vegetative growth that can lead to reduced yield (Miri, 2013). A maximum number of fruits were recorded in sweet orange 'Mosambi' trees where open-canopy was maintained by judicious removal of the leaders, laterals, thin shoots and dead wood (Ghosh & Bera, 2014). On the other hand, girdling alone did not affect increasing fruit number and yield, while it was observed that girdling plus pruning increases yield. Verreynne (2009) stated that girdling is not effective if the fruit is still present on the tree.

Yield is a combination of characters, such as number and size of fruit, plant vigor, hardiness and disease resistance of the plant (Haghighat et al., 2020). The positive and close correlation between yield and fruit number ($r = 1.00$) as well as stepwise multiple regression coefficient suggested that fruit number was the major yield component. According to this, enhancement of fruit number (2.9-fold), provoked by pruning alone and plus girdling, increases yield 2.7-fold compare with control. Similar results have been reported by Rivas et al. (2006) and Ramteke et al. (2015) in mandarin and acid lime, who found that fruit yield was most correlated with the number of fruits per tree.

Pruning and girdling treatments resulted in no significant effects upon the TSS and TA of fruits, while TSS/TA ratio and vitamin C content slightly decreased. The results obtained in the present study are in agreement with those described by Yilmaz et al. (2018), who demonstrates single and double girdling did not significantly affect fruit internal quality of 'Robinson' mandarin.

Physical properties of citrus fruits such as weight, volume, and juice content are important from a marketing point of view (Ladaniya, 2008). Our study demonstrated a high correlation between fruit dimensions with chemical constituents of fruits. Therefore, larger 'Kinnow' mandarin fruits taste sweeter than smaller ones. The lack of significant correlation between fruit weight and fruit dimensions is also evidence that the increase in fruit weight is due to increased juice and biomass, not the height and diameter of the fruit. Kashyap et al. (2020) reported similar results in Khasi mandarin, whereas Mollapur et al. (2016) observed an inverse relationship between fruit weight and fruit flavor in 'Thompson Navel' orange.

CONCLUSION

Crop yield varied significantly according to the pruning and girdling treatments applied during the previous year. The results showed that the fruits of light pruned trees weighed 7.2% less, while the yield and number of fruits increased by 170.4% and 191.5%, respectively. Based on the results, it is recommended to use light pruning alone or with girdling to increase fruit set of 'Kinnow' mandarin trees.

Conflict of interest

The authors have no conflict of interest to report.

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