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A modification in an open centre training system for increasing the crotch angles of peach scaffold branches

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Abstract: One-year-old 'Florida Prince' cultivar peach trees grafted on a 'Nemaguard' rootstock were planted in the early spring of 2018 at the Centre of Agricultural Research and Experiments, Minia University, located in southwest Egypt. The trees were planted 5 × 5 m in a randomised complete block design with four replicates, with ten trees in each replicate. In the late spring, two different pruning systems were applied; traditional open centre (OC) and de-branched top trees (DBT). The OC trees were headed at 80 cm above the ground. DBT is a modification of the OC, but no heading was undertaken and the new shoot growth arising from the 20 cm at the top of the plant were removed. Before the winter pruning took place, measurements were taken on the upper two opposite branches. The average length and diameter values of the upper two opposite branches at the top of the trees trained to the OC were higher than those trained with the DBT. In contrast, the distance between the upper two branches (25 cm) at the top of the DBT trees was significantly higher. Likewise, the values of the crotch angles (48°) and the number of branches (81 of 100 branches) that showed desired crotch angles (more than 40°) were remarkably higher in the trees trained with the DBT. After the winter pruning took place, the DBT trees were higher than the OC trees. Additionally, the trees trained with the DBT had low pruning costs and took less time. Moreover, the pruning wood weight of the DBT trees was about half of the pruning wood weight of the OC trees. In conclusion, the DBT training system showed the desired impact on the crotch angles and the tested pruning characteristics.

Keywords: pruning peach; open centre; pruning modification; fruit training; de-branched top; crotch angles

Tree training systems affect tree growth, light penetration, photosynthesis, and fruit yield, as well as the crotch angles (Barden 1977; Jackson 1980; Ferree et al. 1993; Hampson et al. 2002; Mika, Buler 2015; Casanova-Gascón et al. 2019). An open centre training system (OC) was utilised for improving the tree precocity with better management for the canopy growth (Whiting et al. 2005; Uberti et al. 2019). Generally, OC training is extensively used worldwide for stone fruits (Marini 1990; Hrotkó 2013; Casanova-Gascón et al. 2019), like the peach, apricot, and sweet cherry (Negueroles 2005). Furthermore, the yield of the 'Florida Prince' peach trees is higher when they are subjected to the OC training system in comparison with other training systems like a modified central leader and central leader systems (Fallahi 1992). The traditional OC system contains three to five primary scaffolds (Grossman, De Jong 1998; Uberti et al. 2019). However, improving the OC system abilities by pruning modification was successfully undertaken, i.e., Compact vase and Spanish bush (Hrotkó 2013).

In most cases, peach trees are quite vigorous (Miller, Walsh 1988; Walsh 1992; De Jong et al. 1994). The distribution and development of peach tree branches in the trunk form a reverse coni-

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cal shape (Cook et al. 1999), resulting from heading the parent axis (Champagant 1954; Brown et al. 1967; Crabbé 1987; Cline 1997). The resulting angle between the main branches (Scaffold branches) and the main axis (trunk) is called the crotch angle.

Wider crotch angles, resulting from a strong union between the branches and adjacent tissues, are more favourable, allowing the branches to carry a heavy crop load (Teskey, Shoemaker 1972). On the contrary, narrow crotches have bark inclusion between the branches and the trunk leading to blocking the transport of food reserves in the phloem tissue and a delay in the wood maturation forming a weaker union with soft tissue (Weaver 1968). These tissues may be damaged by winter chilling (Fisher 1990). In addition, narrow crotches are suitable points for insects and disease entry (Weaver 1968; Warner 1991).

Increasing the crotch angles has been achieved by several methods; selecting the proper rootstocks (Warner 1991), spraying with growth regulators (Verner 1939; Williams, Billingsley 1970; Filipovich 1976; Elfving, Forshey 1977), using mechanical forces like bending, cloth pins and sticks (Tustin et al. 1988; Hampson et al. 2004a,b), and applying pruning strategies such as cutting 2/3 of the primary branches, feathering the 1-year-old lateral branches (Preston 1968), heading the current season's growth and leaf removal (Wertheim 1978; Olien 1987), and choosing a proper training system, according to the growth habit of the tree (Jung, Choi 2010; Uberti et al. 2019).

The challenge with widening the crotch angles of the upper tree scaffolds for traditional open centre training is that the lower branches usually have greater angles than the upper ones, regardless of the applied training system (Preston 1968). Therefore, low open centre training, a modification of the traditional OC, was chosen. In which, only the lower branches were selected as scaffolds since the lower branches have wider crotch angles (Marini et al. 1995). This system, however, causes low peach yields (Marini et al. 1995).

Most of the pruning practices for widening the crotch angles were applied in the first year after planting (Campbell, Philips 1980; Sanewski 1988; Marler, Crane 1994; Fumey et al. 2011). Severe summer pruning for increasing the crotch angles in the first year decreased the shoot growth, trunk diameter, and root development (Savage, Cowart 1942; Forshey 1986; Mika 1986; Barden et al. 1989; Miller, Scorza 2010; Pavanello et al. 2018).

Therefore, this study aims to apply a new pruning modification to the traditional open centre training system for increasing the upper branches' crotch angles of 'Florida Prince' peach trees in the first year after planting without the severity of summer pruning. Furthermore, the study investigates the effects of the pruning modification on some plant vegetative growth characteristics and the feasibility of the pruning costs.

MATERIALS AND METHODS

Experimental site. The study was carried out during the 2018 season at the Centre of Agricultural Researchers and Experiments, Minia University, located in Minia governorate (southwest Egypt, 28°15'20''N, 30°34'59''E). The area under investigation is located in an arid region characterised by an evaporation rate of 4 897.91 mm/year. Furthermore, site temperatures vary considerably, especially in the summer, ranging from 7 °C at night to 52 °C during the day, while they do not widely vary during the winter, ranging from 0 °C at night and 18 °C during the day. The annual precipitation in most areas of Egypt is less than 80 mm, while it is about 200 mm in the coastal areas. Additionally, it scarcely rains during the summer, and it is sunny all year round. The orchard soil could be described as a loamy soil with deep underground water (Table 1) which is the main source for the irrigation (Table 2). The physicochemical characteristics of the investigated soil and the irrigation water were analysed at the Soil and Water Analysis Laboratory, Faculty of Agriculture, Minia University, Egypt.

Plant material and treatments. An orchard of ten acres) one acre equals 0.4 hectare) planted with the peach cultivar 'Florida Prince' was chosen. Before the planting, 500 kg of plant origin compost and 150 kg of triple superphosphate were applied per one acre of the experimental area in the planting lines. The 1-year-old nursery trees (one-branch nursery trees, without sided branches) grafted on the Nemaguard rootstock were planted at five meters between plants and five meters between the rows (160 plants per acre) in February 2018. At the planting time, all the plants were cut back at a height of 100 cm to promote the growth of the scaffolds. In the first year of planting (mid-April 2018), all the branches located 40 cm above the ground were removed. Two training groups of summer pruning treatments (Figure 1) were subjected to a randomised complete

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Table 1. Some chemical and physical properties of the site's soil

Soil property	Unit	Value
Chemical properties		
pH (1 : 2.5 water)		8.15
EC	dS/m	1.79
Organic matter	g/kg	11.8
$CaCO_3$	g/kg	39.1
Total N	g/kg	1.5
Available P	mg/kg	14.22
Available K	mg kg	23.10
Soluble cations:		
Soluble Ca^{2+}	mg/kg	133.9
Soluble Mg^{2+}	mg/kg	61.0
Soluble Na^{+}	mg/kg	79.9
Soluble K^{+}	mg/kg	14.6
Soluble anions		
Soluble Cl^{-}	mg/kg	63.1
Soluble SO_4^{2-}	mg/kg	145.2
Soluble CO_3^{2-}	mg/kg	0.0
Soluble HCO_3^{-}	mg/kg	81.7
Physical properties:		
Clay	%	24.22
Silt	%	31.35
Sand	%	44. 43
Texture grade	–	loam
Water holding capacity	%	35.66
Field capacity	%	29.43
Wilting point	%	9.55
Available water	%	19.88

EC – electric conductivity

block design with four replicates (ten plants per replicate), making the total number of the trees utilised for the experiment as 80. The first group was trained according to the traditional open centre (OC) by a heading cut at 80 cm above the ground (Figure 1A). The second group was subjected to a new training system which is a pruning modification of the OC. The trees subjected to the modification training system unreceived the heading back cut (Figure 1B), while the branches positioned in the upper 20 cm of the main stem were removed (de-branched), and that is why the modified training system was called De-Branched Top (DBT). In the fall season (mid November 2018), winter pruning was applied by selecting four to five wide-angled scaffold branches being well-distributed along the mid (about 40 cm above the ground) of the trunk and the top 20 cm in the DBT trees were cut off. All the DBT tree growth stages are shown in Figure 2. Both tree groups were treat-

Table 2. Chemical composition of the well water used for the irrigation

Chemical composition and criteria	Unit	Value
Chemical properties		
pH		7.6
E.C.	dS/m	1.9
Soluble cations		
Soluble Ca^{2+}	meq/L	11.84
Soluble Mg^{2+}	meq/L	11.61
Soluble Na^{+}	meq/L	5.53
Soluble K^{+}	meq/L	0.48
Soluble anions		
Soluble Cl^{-}	meq/L	9.09
Soluble SO_4^{2-}	meq/L	14.98
Soluble CO_3^{2-}	meq/L	0.00
Soluble HCO_3^{-}	meq/L	4.8

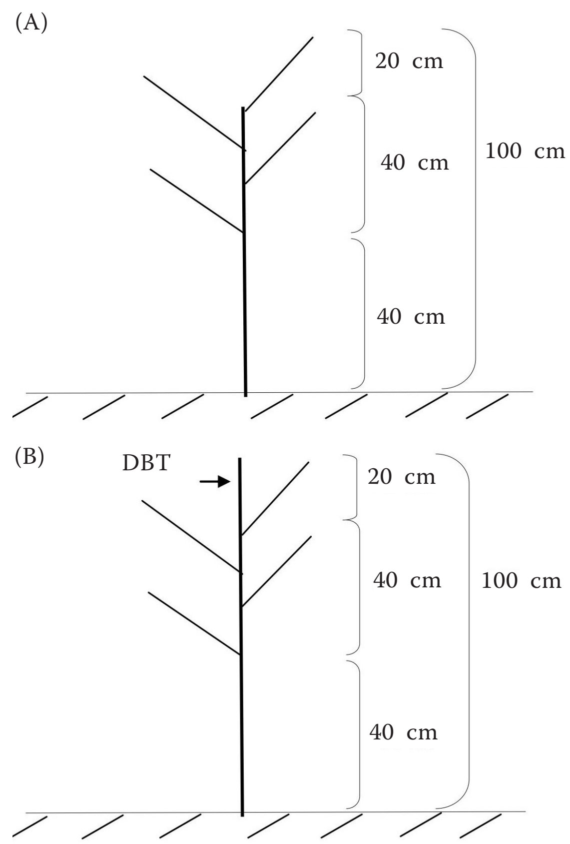

Figure 1. Traditional open centre training system (A), and its modification, the de-branched top system (B)

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ed with the same nutritional practices: 30 kg of N, 15 kg of P_2O_5, 20 kg of K_2O, 15 kg of CaO and 5 kg of MgO per acre. A trickle irrigation system was applied in the orchard, one-line GR-Type emitters per row dripping at 4 L/h, spaced 50 cm apart. The irrigation was designed to depend on a system basis rather than to meet the evaporative demand.The other rec-

Figure 2. The growth stages of the de-branched top trees, (A) after the summer pruning, mid-April 2018, (B) mid-May 2018, (C) mid-August 2018, (D) the fall Season, (E) upper sight after removing the dried top wood only, (F) after the winter pruning, mid-November 2018

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ommended agricultural practices, including pest and weed control, were undertaken during the season.

Data collection. Before the winter pruning, the plant growth characteristics of the upper two opposite shoots in the tree (diameter, length, the distance between them at a height of 100 cm above ground, and the crotch angles) were recorded. Classifications of the crotch angles for 100 branches randomly chosen from all the branches per each treatment were scored, and the tree height was measured. After the winter pruning, the tree height (cm) was measured. The tree trunk diameter at 20 cm above the bud union was recorded and converted to the Trunk Cross-Sectional Area (TCSA). The ratio between the average diameter bases of both the upper two branches/trunk diameter, and the pruning time, weight, and the costs were calculated.

Statistical analysis. The data collected were subjected to an analysis of variance (ANOVA) statistical analysis, at $P \leq 0.05$ and 0.01.

RESULTS

The data presented in Table 3 show the characters of the upper two opposite branches in both the OC and DBT treatments before the winter pruning. The shoot length varied significantly according to the tree training treatments; a higher value was recorded with the OC trees. However, a lower shoot length was detected in the trees trained with the modification (DBT). The same trend in the results was detected regarding the average diameters of the upper two opposite branches. The average diameters of the upper two opposite branches ($P \leq 0.01$) in the DBT trees were less than in the traditional OC trees with values of 1.4 and 2.3 cm, respectively. On the other hand, the DBT system significantly ($P < 0.05$) increased the distance between the upper two opposite branches (25 cm) compared to 10 cm in the trees trained with the OC system.

Before the winter pruning, the training systems affected the crotch angles for the upper two opposite branches as presented in Table 3. The trees trained with the DBT significantly showed wider crotch angles than those trained with the OC, with average crotch angle values of 48° and 28°, respectively.

The results in Table 4 indicated that 81 out of 100 branches displaying the desired crotch angles (more than 40°) were associated with the modification in the DBT trees, while 27 out of 100 branches in the trees trained with the traditional system displayed angles more than 40°.

The results of the average tree height (cm) represented in Table 5 were aversely varied due to the training methods before and after the winter pruning. Before the winter pruning, the average tree height value positively increased with the OC trees, which recorded an average 143 cm in height compared to 121 cm in the DBT trees. The opposite trend was detected after the winter pruning. The DBT trees recorded a higher value in the tree height, surpassing the OC trees by 14 cm in height.

Table 3. The effect of the traditional open centre (OC) training system and its modification, the de-branched top (DBT) system on the characteristics of the upper opposite two branches before winter pruning

Treatments	Characters of upper two opposite branches			
	average length (cm)	average diameter (cm)	average distance apart (cm)	average crotch angles
OC	104	2.3	10	28°
DBT	91	1.4	25	48°
Significance level	*	**	*	**

*Significantly different at a 0.05 probability level; **significantly different at a 0.01 probability level

Table 4. Scoring data of the crotch angle classifications in 100 branches of each system, traditional open centre (OC) training system and its modification, the de-branched top (DBT) training system

Treatments	Crotch angle classification					
	below 31°	31–40°	41–50°	51–60°	61–70°	above 70°
OC	50	23	15	6	4	2
DBT	4	15	32	25	17	7

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Table 5. The effect of the traditional open centre (OC) training system and its modification, the de-branched top (DBT) system on the characteristics of the tree height (before and after the winter pruning), and the tree trunk

Treatments	Tree height (cm)		Trunk diameter (cm)	Between branches diameter / trunk diameter ratio	TCSA (cm^2)
	before winter pruning	after winter pruning			
OC	143	95	4.3	0.54	14.5
DBT	121	109	3.2	0.42	8.0
Significance level	*	*	*	*	NS

*Significantly different at 0.05 probability level; NS – not significant; TCSA – trunk cross-sectional area

The treatments significantly influenced the trunk diameter and the ratio between the upper opposite two branches and the trunk diameter for the trees (Table 5). The values of both traits were higher in the trees trained with the OC training system. The data tabulated in Table 5 show that the values of the TCSA (cm^2) of the OC trees were insignificantly higher than those of the DBT trees.

All the pruning characteristics, as well as pruning cost per tree and acre, were significantly lower with the DBT trees than the OC trees (Table 6). The pruning time of the DBT trees was recorded as 0.17 min per tree and 26 min per acre which was shorter than the pruning time of the OC trees. The modified pruning led to saving the tree wood kg/acre in the first year by about half of the amount removed from the trees subjected to the OC (Table 6). The higher pruning costs ($/tree and $/acre) were recorded in the OC trees with average values of $0.03 per tree and $4.7 per acre, compared to $0.02 per tree and $3.2 per acre with the DBT (Table 6).

DISCUSSION

The OC training system is a matter of choice for peaches and nectarines since they carry fruits on the one-year-old branches (Negueroles 2005). In spite of that, modification trials in the OC training system have been applied to improve the OC training with better canopy growth distributions. Examples of such modifications are the Compact vase and Spanish bush styles (Hrotkó 2013). Originally, this article represents a new modification applied to the OC training system called DBT. All the branches at the top of the DBT trees, about 20 cm of the 100 cm tree height, were removed (de-branched top) in the middle of April (Figures 1B and 2A). Later in winter, this short piece of wood, which is still un-cut, becomes a hard piece of deadwood. The short piece of deadwood simply helps the branches to grow with a wider and desired crotch angle during the growing season. This is a result of the piece serving as a mechanical barrier. So, the de-branched top piece prevented the side branches at the top of the trees from growing directly toward the tree's centre. Consequently, the side branches at the top of the tree grow with wide crotch angles (Figure 2B). The DBT trees were displayed during the season in Figure 2C (mid-August), 2D, and 2E (mid-November, side, and surface view, respectively). Figure 2F shows the tree after the winter pruning took place, showing four wide-angle scaffold branches distributed at the top of the tree with only one branch benched back. During all the growth stages (Figure 2), the trees were not subjected to any other kind of pruning after the middle of April till the winter pruning time, avoiding any problems as-

Table 6. The effect of the traditional OC training system and its modification, the DBT system on some pruning characteristics and the cost

Treatments	Pruning time (min/tree)	Pruning time (min/acre)	Pruning weight (kg/tree)	Pruning weight (kg/acre)	Labour cost ($/tree)	Labour cost ($/acre)
OC	0.76	121.6	0.45	72.	0.03	4.8
DBT	0.59	94.4	0.24	38.4	0.02	3.2
Significancy level	*	*	*	*	**	**

*Significantly different at a 0.05 probability level;**significantly different at a 0.01 probability level

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sociated with severe pruning, which cause the promotion of more shoot regrowth at the first stages, removing carbohydrates from the leaves, decreasing the root development and cytokinin production in the roots (Forshey 1986), and, then, diminishing the shoot growth and trunk diameter, as reported by Savage and Cowart (1942), Forshey (1986), Barden et al. (1989), and Miller and Scorza (2010).

The results in Table 3 display the vegetative growth characteristics of the upper two opposite branches before the winter pruning since these branches are more affected by the type of training system. The lower branches usually have greater angles than the upper ones (Preston 1968; Jung, Choi 2010). Moreover, the upper branches may often be cut off, since they grow vertically toward the tree; centre (Preston 1968). Therefore, assessing the lower branch characteristics was neglected in the present study. Before the winter pruning, the average length of the upper two opposite branches for the OC trees was higher than those for the DBT trees, and the value of the average diameter of the upper two opposite branches for the OC tree was almost two-fold the DBT trees as well. The same results in both traits, the branch length and diameter, were confirmed by several other studies (Jung, Choi 2010; Fumey et al. 2011; Bukovaĉ 2015). The shorter length and diameter in the upper opposite branches with the trees treated by DBT might be attributed to the high light penetration as clearly shown in Figure 2C,D, and F. The light penetration might be higher with the DBT treatment (visual observation) because the distances between the upper two opposite branches in the trees were two-fold the values of those trained with the traditional system (Table 3). These results were confirmed by Jung and Choi (2010), declaring that the light penetration into the canopy was negatively correlated to the shoot length and diameter. Moreover, Robinson and Hoying (2003) suggested that the decrease in the growth of lateral shoots was restricted by the lack of apical auxins on the tips of the shoots.

The average crotch angle for the upper two opposite branches in DBT trees was 42% wider than in the OC trees. Furthermore, the proper crotch angles (more than 40°) in 100 branches were significantly correlated with the DBT training shown in Table 4. The increase of the crotch angles in this study was a result of the mechanical barrier caused by the un-cut short stick (in the DBT) as presented in Figure 2D. It is extremely important that scaffold limbs possess wide crotch angles which contain a strong union between the limbs and trunk, not allowing any scaffold to directly face (which grow vertically) the prevailing wind during the growing season and avoiding branch growth into the open centre (Teskey, Shoemaker 1972; Mika 1986).

The trunk diameter and TCSA values were smaller in the DBT trees (Table 5). Similar results were obtained by Warner (1991) and Whiting et al. (2005). The importance of the ratio between the branch diameter and the trunk diameter was reported by Eisner et al. (2002). When the ratio is relatively low, it forms a strong union between the branch and the trunk as found with the DBT trees (Table 5). The branches of the OC trees were longer (Table 5) since they possess narrow crotch angles receiving less light. In such a case, the branches grow faster and longer. However, after the winter pruning, the trend in the tree height was the opposite. This might be attributed to the intense removal of the top branches from the OC trees as they grew directly upright into the tree's centre.

Generally, the OC training system had the shortest pruning time compared to the other training system (Negueroles 2005), while the modification showed even better results with the pruning time per tree (0.17 min less per tree) compared to the OC training. Subsequently, the DBT had a shorter time for acre pruning (27 min less per acre) (Table 6). This resulted from that more branches were suited to the scaffolds that had the proper crotch angles as represented in Table 4. Subsequently, the pruning cost with the DBT was lower than with the OC (Table 6).

CONCLUSION

Peach plants of the 'Florida Prince' variety were subjected to two different training systems; the traditional open centre training and a modified traditional open centre called de-branched top (DBT). The DBT trees showed wider crotch angles of the upper opposite two branches and a greater number of branches, forming the intended angles compared to the OC trees. Additionally, the trees trained with the DBT system required a shorter pruning time and at a lower cost. The DBT system needs to be investigated more in other peach varieties as well as in stone fruit trees grafted upon different rootstocks to generally confirm its advantages.

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