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The effect of pruning systems on yield and fruit quality of grafted tomato

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ABSTRACT

Vegetable grafting is an increasingly used crop management strategy that aims to prevent soilborne biotic and abiotic stresses. For tomato crops, the number of stems per grafted plant determines planting density and crop exposure to sunlight. The effects of pruning grafted plants on yield and fruit quality have not been established, and this information is crucial to support decision-making by growers. A greenhouse experiment was run in the spring/summer season in the NW Portugal to assess the yield and quality parameters for grafted tomato plants (cv. Vinicio grafted onto Multifort rootstock) pruned to 2, 3 and 4 stems developed from the plant first nodes, or pruned to 2 stems developed from cotyledonary nodes, according to common practice. Total yield was significantly increased for the double-stemmed tomato plants, irrespectively of node origin (average yield 26.5 kg/m^2), as compared to the 3- and 4-stemmed plants (average yield 19.5 kg/m^2). These results can be explained by root system limitations to uptake water and nutrients coupled with the stronger competition between stems for the 3- and 4-stemmed plants. Fruit quality assessed through firmness (1.0 kg/cm^2), soluble solids (5.1°Brix), acidity (1.0 g/100 g fresh weight), pH (4.4) and dry mater content (4.9%) was not affected by pruning systems. The greater yield obtained from double-stemmed plants offsets the increased planting and seedlings costs of using grafted tomato plants, particularly so for double-stemmed plants grown from first nodes, as they do not require intensive nursery care and are therefore less costly than those grown from cotyledonary nodes.

Keywords: *Solanum lycopersicum*, cotyledonary and plant nodes, Multifort rootstock, stem number, vegetable grafting.

RESUMO

Efeito do sistema de condução na produtividade e qualidade dos frutos de tomateiro enxertado

O uso da enxertia na horticultura tem aumentado como estratégia de prevenção de estresses bióticos e abióticos de origem edáfica. Na cultura de tomate em estufa o número de hastes por planta enxertada, que determina a densidade de plantio e exposição solar da cultura, deve ser investigado para uma correta gestão da cultura. Foi realizado um ensaio em estufa durante a primavera/verão no NW de Portugal com o objetivo de avaliar os efeitos na produtividade e qualidade dos frutos de tomateiros enxertados (cv. Vinicio em porta-enxerto Multifort), da condução em 2, 3 e 4 hastes por planta, a partir dos nós das primeiras folhas definitivas ou com 2 hastes a partir dos nós das folhas cotiledonares, o que reflete as práticas usuais com tomateiro enxertado. A produtividade foi significativamente superior para as plantas de tomateiro conduzidas com 2 hastes (26,5 kg/m^2), comparativamente com plantas de 3 e 4 hastes (19,5 kg/m^2), o que poderá estar relacionado com uma maior competição por água e nutrientes entre as hastes da mesma planta, bem como por limitações do sistema radicular das plantas com 3-4 hastes. Os parâmetros de qualidade dos frutos como firmeza (1,0 kg/cm^2), teor em sólidos solúveis (5,1°Brix), acidez total (1,0 g/100 g de peso fresco), pH (4,4) e matéria seca (4,9%) não foram influenciados pelos sistemas de condução. A maior produtividade das plantas conduzidas em 2 hastes compensou os custos mais elevados da plantação de plantas enxertadas. Os resultados idênticos das plantas conduzidas em duas hastes a partir dos nós das folhas cotiledonares e das primeiras folhas definitivas, sugerem que as primeiras não devem ser recomendadas pois requerem cuidados acrescidos de produção no viveiro.

Palavras-chave: *Solanum lycopersicum*, enxertia de oleráceas, nós das folhas verdadeiras e cotiledonares, número de hastes, porta-enxerto Multifort.

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Worldwide intensification of vegetable crop production increased soil pests and diseases and soil accumulation of undesirable chemical compounds. Vegetable grafting has been safely adapted to mitigate these problems, with particular relevance for organic crop protection, where the application of synthetic pesticides is forbidden (Hasna *et al.*, 2009; Lee *et al.*, 2010). Plants grafted onto vigorous rootstocks are more robust and generate higher yields, whilst decreasing the required planting density and lowering irrigation requirements due to their extensive root systems. Vegetable grafting on compatible, successful scion-rootstock combinations also allows the efficient maintenance of local vegetable cultivars, for crops such as tomato, pepper, eggplant, cucumber,

melon and watermelon (Lee *et al.* 2010; Savvas *et al.*, 2010).

Grafting tomato plants can induce resistance/tolerance to various soil diseases such as *Pyrenochaeta lycopersici* (corky root rot), *Fusarium oxysporum* f. sp. *lycopersici*, *Ralstonia solanacearum* and *Verticillium albo-atrum* (Theodoropoulou *et al.*, 2007; Rivard & Louws, 2008; Hasna *et al.*, 2009; Louws *et al.*, 2010). Grafting may also provide resistance to nematodes (Rivard *et al.*, 2010; Rumbos *et al.*, 2011) and to tobacco mosaic virus (TMV) (McAvoy *et al.*, 2012). Vegetable grafting on selected rootstocks can also effectively increase plant tolerance to abiotic stresses by temperature and salinity, as well as improve plant nutrient uptake and nitrogen use efficiency, which in turn can mitigate yield losses in nutrient-poor environments (Colla *et al.*, 2010; Savvas *et al.*, 2010, 2011; Fan *et al.*, 2011; Schwarz *et al.*, 2013).

The sugars and acid composition of tomato largely determine its flavour quality. High contents of sugars (soluble solids, SSC) and titratable acids (TA) are considered parameters of good taste and flavour (Kader, 2008). Some tomato rootstocks are able to induce significant increases in fruit SSC and TA for crops grown under optimal conditions, but these effects seem to be dependent on both the scion and rootstock genotypes (Flores *et al.*, 2010; Rouphael *et al.*, 2010). Although grafting for some tomato scion/rootstock combinations can lead to an increased TA and decreased SSC (Schwarz *et al.*, 2013), Savvas *et al.* (2011) found that fruit quality characteristics were not affected by grafting or the rootstock genotype.

Ungrafted tomato plants are usually pruned as single-stemmed plants, but grafted plants can support two or more stems, and this allows growers to decrease planting density whilst maintaining stem density, with similar crop exposure to sunlight. Growers therefore use grafted tomato plants pruned to at least two stems, and tend to increase the number of stems per grafted plant in order to decrease planting labour and seedling costs. Some growers also select plants with stems developed from the cotyledonary nodes, as the closer scion proximity to the rootstock is thought to improve the flow of water and nutrients from the root to the shoot. However, a quantification of the effects of different commonly used pruning systems on yield and fruit quality of grafted tomato plants to support growers' decisions is lacking. This study aims to evaluate the effects of pruning to increasing numbers of stems (2, 3 or 4) and on the stem node origin (first true leaves or cotyledonary leaves) on tomato yield and fruit quality of grafted plants.

MATERIAL AND METHODS

An experiment was conducted with grafted tomato plants under unheated greenhouse conditions, during spring/summer 2013, at Santo Tirso, NW Portugal (41º20'42''N, 8º28'18'W), in a Cambisol with a sandy loam texture, pH (H_2O) 6.2, high level of organic matter (54 g/kg), high nutrient content (579 mg/kg P_2O_5 and 368 mg/kg K_2O estimated by the Egner-Rhiem method of Egner *et al*. (1960); 2810 mg/kg total Ca and 117 mg/kg total Mg) and with high electrical conductivity (3.6 dS/m). A randomized block design with three replications and four treatments was used to evaluate crop yield and quality. Treatments included three pruning systems of tomato grafted plants with 2, 3 and 4 stems developed from the plant first nodes (P2, P3, P4) and one pruning system with 2 stems developed from cotyledonary nodes (P2c) (Figure 1). These treatments aimed to encompass grafted tomato pruning systems commonly used by growers in Portugal.

Grafted tomato plants were obtained from a nursery, Germiplanta Ltda., Leiria, Portugal, where they were produced through splice grafting to our custom order according to commercial practices. Beef type tomato cv. Vinicio (E27.33490) was grafted onto the inter-specific hybrid rootstock Multifort (*S. lycopersicum* x *S. habrochaites*; Naktuinbouw, 2014) and grown at a stem spacing of 0.5 m in the line and 0.8 m between lines, in a plant density of 1.25, 0.83 and 0.63 plants/m^2, respectively for the 2-, 3- and 4-stemmed plants. The total number of plants in each treatment plot were respectively 12, 8 and 6 plants and two plants were evaluated per plot. A commercial organic fertilizer produced from vinasse, molasses, bone meal and feather meal was applied at a rate of 2 t/ha, with 91±1% dry matter, pH 5.3±0.03, electrical conductivity 9.0±0.2 dS/m, organic matter 942±2.7 g/kg and C/N 6.9±0.02. The nutrient composition of this organic fertilizer for the N, P, K, Ca, Mg and Fe was, respectively, 76.1±23.0, 2.2±1.0, 35.0±8.0, 11.9±3.0, 2.2±0.5 and 0.6±0.2 g/kg DM and the estimated total organic N applied was 139.0 kg/ha. The soil was covered with a black landscape fabric with a thickness of 100 µm (Figure 1) and the nylon strip tutors were at 2.5 m height.

The mean daily air temperature throughout the growing period was 20.6°C and ranged from 26.5 to 11.0°C. Plant protection included the application of the predator *Nesidiocoris tenui* (Heteroptera: Miridae) to control *Tuta absoluta* and white flies (*Bemisia* spp. and *Trialeurodes* spp.), applied 45 days after planting; sulphur to control the mite *Aculops lycopersici*, compatible with the auxiliary *N. tenui*. The irrigation was performed by a drip system, with drippers spaced at 0.30 m with 4 L/h flow rate. Bumblebees (*Bombus terrestris*, Beeline bb Bioline Syngenta) were used for pollination.

The first harvest took place on the 25th June (104 days after planting) and the last harvest on 24th September (195 days after planting). During the 91-day harvesting period, two plants per treatment and replicate were harvested weekly (14 harvests). The number of fruits as well as fresh weight for each of the following grades: ≤57, 57-66, 67-81, 82-102 and >102 mm, were recorded. The firmness, pH, total soluble solids content, titratable acidity and dry weight were evaluated through European Standard Norms for five harvests during the harvesting period. Fruit firmness was determined with a penetrometer (TR Snc), soluble solids were quantified with an ABBE refractometer (Vitrilab), pH was measured with a potentiometer and the acidity by titration at pH 8.1 with a

solution of 0.1N NaOH, and expressed as a percentage of citric acid (ISO 750, 1998). Fruit dry matter content was determined after drying the fruit in a ventilated oven at 70°C for 48 hours.

Analysis of variance (ANOVA) was performed by the general linear model SPSS procedure using SPSS 17.0 for Windows (SPSS Inc.) and treatments were compared by the least significant difference (LSD) test. A probability level of $\alpha = 0.05$ was applied to determine statistical significance.

RESULTS AND DISCUSSION

The initial stem architecture of grafted tomato plants of treatments P2c, P2, P3 and P4 is presented in Figure 1. The first cluster blossom occurred between 49 and 56 days after planting (DAP), without significant differences between the different number of stems treatments. However, the first complete fruit cluster occurred earlier (average 72 DAP) in plants developed from first true leaf nodes, independently of the number of stems (treatments P2, P3, P4). Double-stemmed plants developed from the cotyledonary nodes (P2c) grew their first complete fruit cluster 7.5 days later. The timing of production can be critical for growers, with earlier tomato production reaching higher market prices. The one-week delay in production of the first fruit cluster from P2c plants is therefore undesirable. Furthermore, the percentage of fruit set was smaller for P2c compared to P2 and P4 treatments. In terms of fruit grade, the overall mean weight of single fruits was 220 g, the percentage of fruit grade between 57-102 mm was 96.3% of total yield and the fresh weight of larger fruits (>102 mm) was similar for all plant treatments, but fresh weight of smaller fruits (≤56 mm) was smaller for P3 (Figure 2).

The total number of fruit clusters per plant was similar for the double-stemmed plant treatments (both P2 and P2c) (mean of 20.0) but lower ($p<0.05$) than that of the 3- and 4-stemmed plants (mean of 28.9). However, the number of clusters per stem was 7.5 in the P4 plants which was significantly lower ($p<0.05$) than that of P2 plants, with a mean of 10.4 clusters (Table 1). This resulted in significantly larger fruit numbers and significantly higher yield from double-stemmed plants, irrespectively of stem node origins, as presented in Table 1. Therefore, contrary to empirical observations from growers, using grafted plants with stems originating from cotyledonary leaf nodes does not seem to be advantageous in terms of yield over those with stems originating from first true leaf nodes. Likewise, although growing 3- or 4-stemmed plants allowed for a reduced planting density (with a corresponding reduced number of plants grown), the yield per area was significantly smaller than that obtained from double stemmed plants.

The smaller tomato yield obtained from P3 and P4 can be explained by a stronger competition between stems within the plant for water and nutrients, as well as root system limitations of the 3- and 4- stemmed plants to cope with the increased water and nutrient

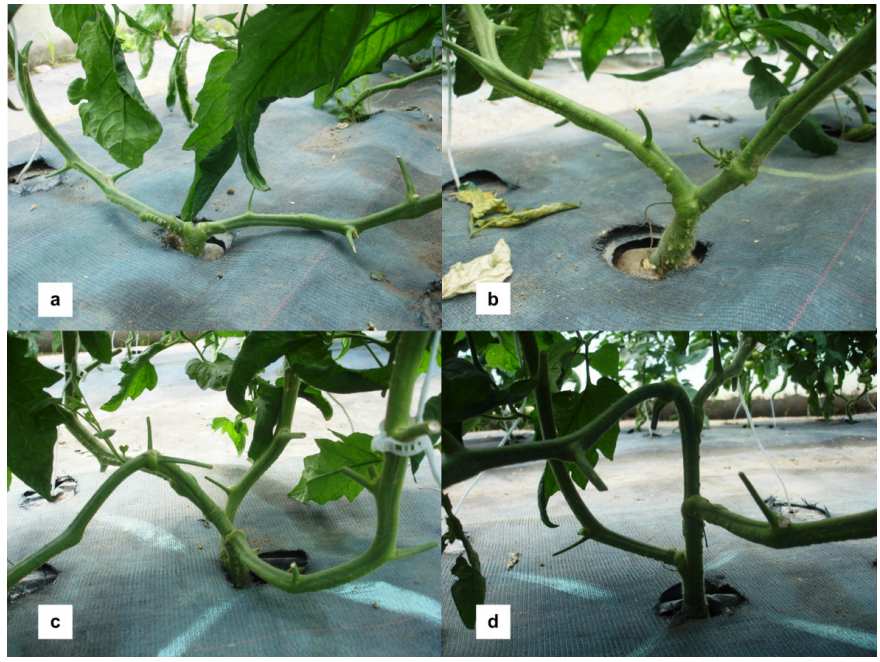

Figure 1. Tomato plants (cv. Vinicio) grafted onto inter-specific hybrid rootstock Multifort, pruned with (a) 2 stems developed from cotyledonary nodes and pruned with (b, c, d) 2, 3 and 4 stems developed from the plant first nodes, for crops grown under unheated greenhouse conditions, during the spring/summer. Santo Tirso, Portugal, EPACSB, 2013.

Table 1. Mean cluster sets (nº/stem and nº/plant), total number of fruits (nº/m²) and total crop yield (kg/m²), for grafted tomato plants with 2 stems developed from the cotyledonary nodes (P2c) and with 2, 3 and 4 stems developed from the plant first nodes (P2, P3, P4), for crops grown under unheated greenhouse, during the spring/summer. Santo Tirso, Portugal, EPACSB, 2013.

Treatments	Cluster sets (nº/stem)	Cluster sets (nº/plant)	Fruits (nº/m²)	Yield (kg/m²)
P2c	9.6 ab	19.2 b	121.5 a	25.79 a
P2	10.4 a	20.8 b	125.0 a	27.22 a
P3	9.3 ab	28.0 a	82.9 b	18.79 b
P4	7.5 b	29.8 a	89.0 b	20.15 b
CV (%)	13.8	20.0	5.8	7.8

Different letters in each column mean significant differences between crop treatments, by the LSD test ($p<0.05$) {letras diferentes em cada coluna significam diferenças significativas entre os tratamentos, pelo teste DMS, ($p<0,05$)}.

demand. This agrees with findings that double-stemmed compared to 3-stemmed ungrafted tomato plants (cv. Bari) led to an increased marketable yield and similar single fruit weight (Ara *et al.*, 2007), and the report that single-stemmed ungrafted plants of organic cherry tomato (cvs. hybrid Super Sweet and a self-pollinated Perinha) showed increased total and commercial yield compared to double-stemmed plants, also with similar average fruit weight (Azevedo *et al.*, 2010).

This apparent competition effect between stems originating from the same root system is expected to be modulated by soil fertility and water availability. In high soil fertility conditions, tomato cv. Valoásis M40 F1 grafted onto rootstocks Maxifort resulted in similar number of fruits, mean fruit weight and total yield for 2- and 3-stemmed plants. But, yield in grade >102 mm, which represented 76% of total yield, was still significantly larger in double-stemmed plants (Mourão *et al.*, 2013).

The percentage of unblemished fruits (91%) was not affected by the pruning treatment. However, fruits with healed cracks were more frequent for P2 and P4 (8.0%) than in the other stem treatments (5.6%). Fruit quality was not influenced by the pruning system because differences between treatments on fruit firmness (average 1.0 kg/cm^2), content of soluble solids (average 5.1°Brix), acidity (average 1.0 g/100 g), pH (average 4.4) and dry mater content (average 4.9%), were not significantly different, as reported in previous studies (Ece & Darakci, 2009; Franco *et al.*, 2009; Mourão *et al.*, 2013). For example, the dry mater content, pH and ascorbic acid values were similar between single and double-stemmed plants for 34 tomato cultivars reported by Ece & Darakci (2009). However, Ara *et al.* (2007) reported that fruits of double-stemmed plants had higher wall thickness and content of soluble solids, compared to fruits of 3-stemmed plants, whereas Abdel-Razzak *et al.* (2013) suggested that single-stemmed plants exhibited improved fruit quality (dry matter, titratable acidity, vitamin C, total soluble solids and total sugars) compared to double-stemmed plants.

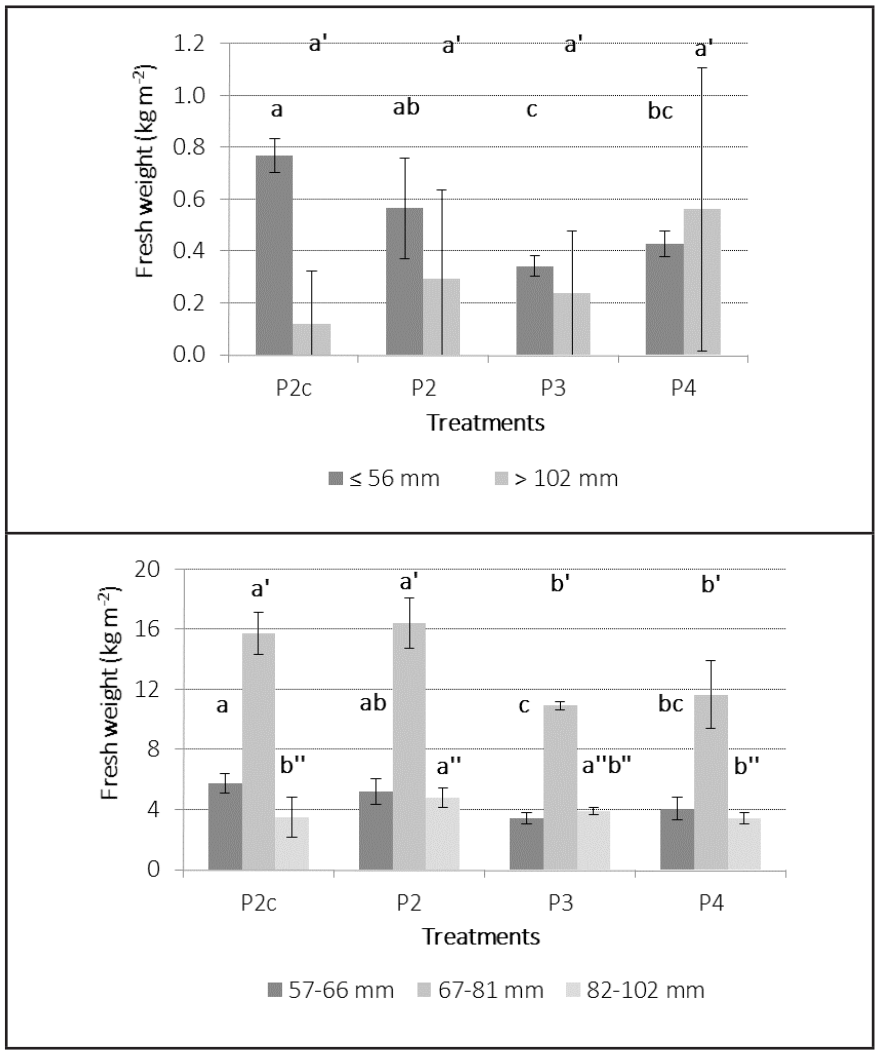

Figure 2. Tomato fresh weight (kg/m^2) for fruit grade ≤56, 57-66, 67-81, 82-102 and >102 mm, for grafted tomato plants with 2 stems developed from cotyledonary nodes (P2c) and with 2, 3 and 4 stems developed from the plant first nodes (P2, P3, P4), for crops grown under unheated greenhouse conditions, during the spring/summer. Different letters above bars mean significant differences between crop treatments, by the LSD test, ($p < 0.05$). Error bars represent standard deviation. Santo Tirso, Portugal, EPACSB, 2013.

In our study, a single-stemmed grafted tomato plant treatment was not included, as this is not common practice amongst growers, who tend to use grafted tomato plants partly because they can be grown with up to four stems, thus reducing planting density whilst putatively increasing yield. Our results have shown otherwise: fruit yield and quality was higher for double-stemmed plants than for 3- and 4-stemmed plants. It is not clear, however, whether single-stemmed grafted plants would produce fruit with comparable quality parameters and yield as double-stemmed plants.

Taking into account the price of grafted plants (0.71 €/plant), the differences between plant density of 2, 3 and 4 stems (respectively 1.25, 0.83 and 0.63 plants/m^2), the yield increase (7.0 kg/m^2) and the mean price of tomato (0.50 €/kg), the gross income with the double-stemmed grafted tomato plants could increase by approximately 3.0 €/m^2 compared to 3- and 4-stemmed plants.

In conclusion, the use of double-stemmed grafted tomato plants may be recommended for greenhouse cropping, because the observed yield increase would offset the planting labour and seedlings costs for this

pruning system, compared to the 3- and 4-stemmed plants. It also became apparent that the increased yield in doublestemmed plants is independent of node origin, and therefore using grafted tomato plants pruned to two stems originating from first true leaf nodes should be recommended, as the production of these plants requires less nursery pruning care (further reducing expenses). Furthermore, plants whose stems were obtained from first true leaf nodes initiated production significantly earlier than those with stems obtained from cotyledonary leaf nodes, which may also be advantageous for producers.

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