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Abstract

Tomato landrace producers are adopting grafting technology to overcome agronomic deficiencies and increase plant yields. Landraces are valued for their higher organoleptic quality, so it is important to assess the impact of grafting on their sensory profile. We studied the influence of ‘Beaufort’ rootstock on agronomic, morphologic, and sensory traits using two landraces (‘Mando’ and ‘Montgri’) and one commercial cultivar (‘Egara’) as scions in two extreme management systems for tomato cultivation: conventional/greenhouse and organic/open. Panel sensory analysis found that grafting onto ‘Beaufort’ had a negative effect on sensory attributes, reducing sweetness, acidity, and intensity of flavor in the organic system and sweetness and intensity of flavor in the conventional system. In conventional management, grafting also modified some aspects of fruit appearance. In the conventional system, grafting significantly increased yield in all the genotypes (mean increase, 52%). By contrast, in the organic system, grafting increased yield only in the ‘Mando’ landrace (mean increase, 62.3%). As many genotype × grafting interactions affecting many important commercial traits occurred in both management systems, specific studies with different rootstock-scion combinations are highly recommended before adopting this technique for producing landraces with high sensory quality.

Keywords (separated by '-') Organic farming - *Solanum lycopersicum* L. - Organoleptic quality - Rootstock - Sensory analysis

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RESEARCH REPORT

Cultivation Physiology

Impact of grafting on sensory profile of tomato landraces in conventional and organic management systems

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Abstract

Tomato landrace producers are adopting grafting technology to overcome agronomic deficiencies and increase plant yields. Landraces are valued for their higher organoleptic quality, so it is important to assess the impact of grafting on their sensory profile. We studied the influence of 'Beaufort' rootstock on agronomic, morphologic, and sensory traits using two landraces ('Mando' and 'Montgri') and one commercial cultivar ('Egara') as scions in two extreme management systems for tomato cultivation: conventional/greenhouse and organic/open. Panel sensory analysis found that grafting onto 'Beaufort' had a negative effect on sensory attributes, reducing sweetness, acidity, and intensity of flavor in the organic system and sweetness and intensity of flavor in the conventional system. In conventional management, grafting also modified some aspects of fruit appearance. In the conventional system, grafting significantly increased yield in all the genotypes (mean increase, 52%). By contrast, in the organic system, grafting increased yield only in the 'Mando' landrace (mean increase, 62.3%). As many genotype × grafting interactions affecting many important commercial traits occurred in both management systems, specific studies with different rootstock-scion combinations are highly recommended before adopting this technique for producing landraces with high sensory quality.

Keywords Organic farming · *Solanum lycopersicum* L. · Organoleptic quality · Rootstock · Sensory analysis

1 Introduction

Some tomato growers in Europe are showing renewed interest in landraces that can be sold at premium prices. Although landraces occupy a low proportion of the area cultivated with tomatoes (< 5% of the total in Catalonia), some farmers consider that this strategy frees them from competition with high-yield, low-cost tomatoes from foreign producers (Cebolla-Cornejo et al. 2007). However, landraces pose several problems for growers and retailers. First, although consumers recognize the landraces by their characteristic appearances (Casals et al. 2011; Mazzucato et al. 2010), high genetic variability within landraces for other important traits like nutritional value or sensory profile can undermine consumer loyalty (Casals et al. 2011; Cortés-Olmos et al. 2015). Growers need to identify genotypes that combine the typical appearance of the variety with good agronomic performance without diminishing their high sensory and/or nutritive quality profile. Second, landrace cultivars have little or no resistance to multiple diseases that affect tomato crops, including soil-borne diseases (Acciarri et al. 2007) and viruses (Pico et al. 2002), which can lead to dramatic decreases in yield.

Grafting in horticulture has spread rapidly in recent years (Fan et al. 2015). In tomatoes, it was initially used to improve resistance to different stresses, including both abiotic stresses [low and high temperatures (Rivero et al. 2003), salinity (Estañ et al. 2005, 2009), and low nutrient and water availability (Schwarz et al. 2010, 2013)] and biotic stresses [soil-borne diseases such as bacterial wilt caused by *Ralstonia solanacearum,* fusarium wilt caused by *Fusarium oxysporum* f. sp. *lycopersici*, and nematodes (Rivard and Louws 2008; McAvoy et al. 2012)]. Nowadays, grafting

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is widely used to increase plant yield (Flores et al. 2010) and has caught the attention of farmers growing traditional landraces. However, the effect of grafting on sensory quality attributes is uncertain. Different studies have reported that grafting increases, decreases, or does not affect sugar and acid concentration (Di Gioia et al. 2010; Flores et al. 2010; Savvas et al. 2011; Barrett et al. 2012; Krumbein and Schwarz 2013; Schwarz et al. 2013). Moreover, grafting also affects the volatile compounds responsible for tomato aroma and taste: Krumbein and Schwarz (2013) reported a significant decrease in carotenoid-derived volatiles and an increase in lignin-derived volatiles in grafted plants. These changes should have an impact on the sensory profile of the tomatoes and therefore on their economic value. Nevertheless, the few studies that have assessed the effect of grafting on tomatoes' organoleptic profile through descriptive sensory analyses (Di Gioia et al. 2010; Barrett et al. 2012) have yielded inconclusive results.

Furthermore, the impact of grafting on some agronomic and compositional traits is highly dependent on the rootstock/scion combination (Estañ et al. 2009; Rouphael et al. 2010) and on environmental conditions (Flores et al. 2010), making it difficult to compare studies and draw general conclusions. Thus, tomato landrace growers lack reliable information to decide whether grafting with a given scion/rootstock/environment combination will increase yields without negatively affecting the sensory profile on which their price depends.

In this study, we aimed to assess the effect of 'Beaufort', the most common rootstock used in Northeast Spain, on sensory profile and agronomic performance in two widely grown local landraces and one commercial cultivar of tomato. To determine whether the effects of grafting are consistent across environments, we conducted the trials in two extreme growing conditions: greenhouse/high-input and open field/organic managed cultures. To ensure that the results would be applicable to farmers' real field conditions, plants in each environment were managed with the specific procedures used for commercial production in each.

2 Materials and methods

2.1 Plant materials and growing conditions

We chose three tomato (*Solanum lycopersicum* L.) varieties ('Mando', 'Egara', and 'Montgri') to represent different pedigree groups within the fresh tomato type. 'Mando' is a pure line landrace that has not undergone any scientific breeding processes; historically cultivated in low-input fields in Collserola natural park (Northeast Spain), it produces large flat fruits with red external color. 'Montgri' is an improved pure line obtained through selection for high agronomic performance and sensory profile within the Pera Girona landrace (Casals et al. 2010) that produces intermediate-sized obovoid fruits with pink external color. 'Egara' is a multiple-resistant, high-yielding hybrid widely grown in Northeast Spain since first marketed in 2011 (Semillas Fito, Barcelona, Spain) that produces intermediate-sized round-to-flat fruits with red external color. The 3 varieties have an indeterminate growth habit. Plants of each variety were grown with their own roots and grafted onto the interspecific (*S. lycopersicum* L. × *S. habrochaites* S. Knapp & D.M. Spooner) rootstock 'Beaufort' F1 (De Ruiter Seeds/Monsanto, Bergenschoenk, the Netherlands).

Experiments were conducted at two locations in Catalonia (Northeast Spain). In one location (Argentona, 41°33′N, 2°24′E, 88 m asl), a conventional cropping system was used; in the other location (Cerdanyola, 41°28′N, 2°7′E, 82 m asl), an organic cropping system was used. Rather than using the same plant growing techniques in both locations, we decided to perform the experiment by following the specific management techniques used in each environment (farmers' standard practices). Although this approach does not allow us to compare across environments, the results provided are closer to farmers' actual field conditions. In each location, all the scion × grafting combinations were studied, thus yielding 6 grafting combinations: 'Montgri'/non-grafted, 'Montgri'/'Beaufort', 'Mando'/non-grafted, 'Mando'/'Beaufort', 'Egara'/non-grafted, 'Egara'/'Beaufort'. Grafting and initial stages of plantlet development were carried out in controlled conditions in a nursery; plants were transplanted when they reached a height of 15–20 cm. The experiment in Argentona was carried out in a 1.5 ha plastic multi-span greenhouse (flat arch type) that was passively ventilated with roof vents. Plants were grown in the soil using modern commercial tomato cultivation practices: grafted plants were conducted vertically on two stems using the V-shape method at a density of 2 plants m^{-2} and non-grafted plants on one stem at a density of 4 plants m^{-2}. A randomized complete block design with 3 replications was used, with 10 plants per plot. Thus, each grafting × genotype treatment was studied in triplicate (30 plants per combination). Plants were irrigated daily with drip tapes, adapting the water volume to the evapotranspiration of the crop, and reaching a maximum of 2.69 l plant^{-1} day^{-1}. To ensure maximum yields, we applied a fertigation schedule, splitting an overall rate of macronutrients ($N = 400$ kg ha^{-1}, $P_2O_5 = 150$ kg ha^{-1}, and $K_2O = 600$ kg ha^{-1}) distributed throughout the crop season in weekly applications (fertilizers: potassium nitrate, calcium nitrate, monopotassium phosphate, potassium sulfate, and magnesium sulfate). Fertilizers were combined and adjusted each week to reach the estimated rates of daily uptake of N, P, and K per plant described by Bar-Yosef (1977) for each developmental stage. Lateral stems were pruned every week, and lower leaves were removed from plants under trusses in which all the fruits had ripened. Fruits at breaker stage were harvested once a week to estimate yield parameters. Pests and diseases were managed using integrated pest control procedures: to control caterpillars (*Tuta absoluta* and *Helicoverpa armigiera*), *Macrolophus pygmaeus* (released twice), and *Bacillus thuringiensis* (applied 5 times); to control fungal diseases, sulfur and copper (applied every 15 days); to control *Aculops lycopersici*, abamectin (Vertimec®) and spiromesifen (Oberon®). Weeds were controlled using black polyethylene plastic mulch. To promote pollination, bumblebees (*Bombus terrestris* L.) were introduced at a density of 6 hives/ha.

In Cerdanyola, plants were grown using traditional tomato growing techniques in the open air in a field managed organically for at least 10 years. Grafted and non-grafted plants were conducted vertically on single stems and supported with canes at a density of 2 plants m^{-2}. The experimental design was similar to that used in Argentona, with a randomized complete block design with 3 replications, with 10 plants per plot. Plants were furrow-irrigated (once a week the plot was flooded to field capacity) and were fertilized with a single application of cow manure prior to planting (30 t ha^{-1}). Lateral stems were pruned every week, and lower leaves were left on the plant. Fruits at breaker stage were harvested once a week to estimate yield parameters. Pests and diseases were managed according to organic farming protocols; the crop was sprayed only with products whose sole active ingredients were *Bacillus thuringiensis*, sulfur, and copper. Weeds were controlled manually.

The two experimental locations are near each other (25.4 km apart) and have similar edaphic qualities (sandy loam soils, organic matter content 0.75% in Argentona and 2.3% in Cerdanyola, electrical conductivity 0.160 dS/m in Argentona and 0.143 dS/m in Cerdanyola, pH 7.3 in Argentona and 8.0 in Cerdanyola). Soil pH values in both locations are higher than those recommended for tomato cultivation (6.0–6.5) (Csizinszky 2005). Climatic conditions were different in the two locations, with temperature and relative humidity higher in Argentona (mean values: 24.0 °C, 71.1%) than in Cerdanyola (22.0 °C, 61.3%) (Fig. 1). The cropping season was the same in both locations (year 2014; planting 01 May; end of the cropping season 15 September; number of days of cultivation: 138).

2.2 Agronomic, visual sensory (morphologic), and chemical traits

To assess the effect of grafting on agronomic performance, we recorded the weight of all the individual fruits from each plant and calculated the following variables: fruit weight (g), yield (kg m^{-2}), number of fruits per m^{-2}, and fruit-weight heterogeneity (coefficient of variation of the weight of the individual fruits within plants, in %). Fruits affected by physiological disorders (blossom-end rot (BER) and fruit cracking) were also recorded. Twenty fruits from each treatment (variety/grafting/management system), harvested at the red ripe stage from the third to fourth truss and representative of the different plants, were used to study the following morphological traits: width (mm), length (mm), locular relative

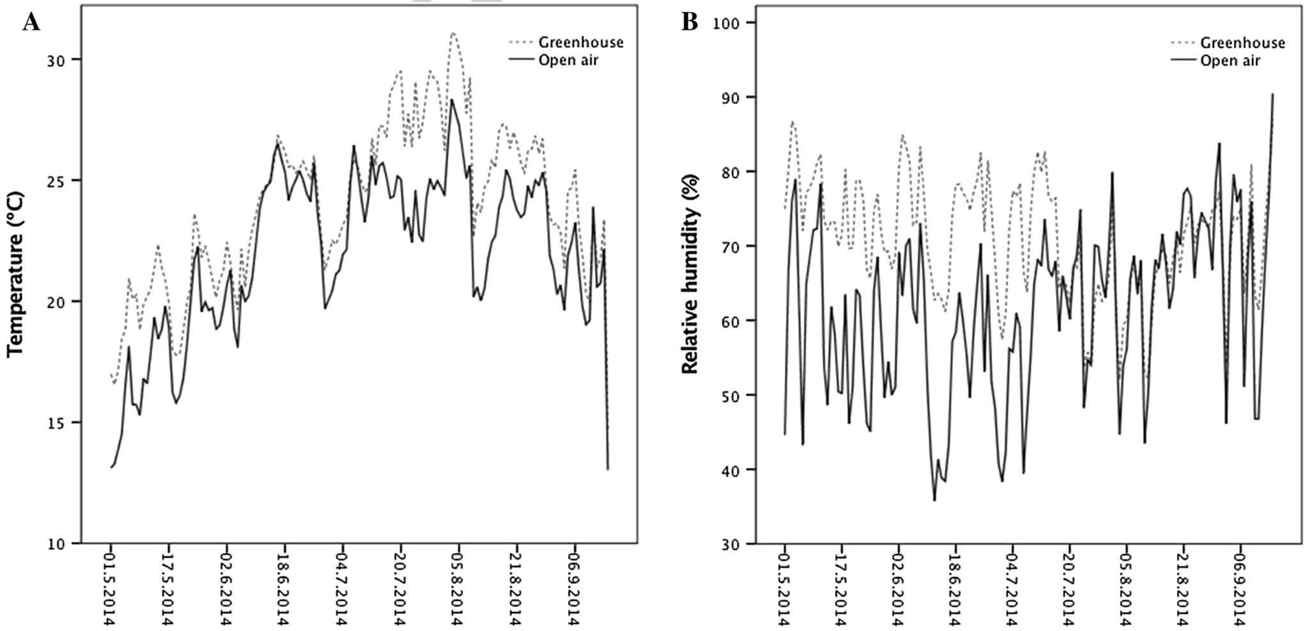

Fig. 1 Temperature (**a**) and relative humidity (**b**) recorded in the experimental fields during the cropping season

content (ratio of the weight of locular jelly plus placental tissue to the total fruit weight, in %), and pericarp thickness (ratio between the double of the pericarp thickness and the width of the fruit, mean of 3 measures per fruit, in %). For each of the 20 fruits, we recorded the soluble solids content (SSC) using a hand-held ERMA refractometer (0–18%). SSC was measured at room temperature (approximately 20 °C) in duplicate from a single drop of tomato puree prepared from each fruit in a laboratory blender after washing, drying, and removing the lignified zone at the proximal end.

2.3 Texture and taste sensory traits recorded by trained panel

For sensory analysis, 20 table-ripe tomatoes were harvested from the second to fourth trusses from each variety * treatment * management under study. Fruits of each variety were selected using the same criteria as for morphological phenotyping. The selected fruits were washed with cold running tap water and dried with absorbent paper. Nine trained panelists with over 7 years' experience in tomato evaluation (Casals et al. 2011) carried out a quantitative descriptive analysis of the fruits. Initially, panelists were selected from the employees of the Barcelona School of Agricultural Engineering, and their ability to perform sensory analysis was validated through several standardized tests according to the indications of the International Organization for Standardization (ISO 1988). The panel's scientific soundness has been demonstrated through several works in different species, e.g. in tomato (Casals et al. 2011), beans (*Phaseolus vulgaris* L.) (Romero del Castillo et al. 2008), or onions (*Allium cepa* L.) (Simo et al. 2012). All sensory sessions took place in individual booths meeting the standards specified by the International Organization for Standardization (ISO 1998) under red light to mask the color of the samples. Samples were coded with 3-digit random numbers and each panelist evaluated the products in random order.

Panelists evaluated the attributes reported to have the greatest impact on consumer preferences: sweetness, acidity, overall taste intensity, skin perceptibility, and pericarp mealiness (Causse et al. 2010). To avoid intra-batch variability, taste-related attributes (sweetness, acidity, and taste intensity) were evaluated on a puree of at least 10 tomatoes. Texture-related attributes were evaluated on 2 cm wide longitudinal slices. For each cropping system, the variety * grafting combinations were assessed in triplicate in different sessions, each consisting of a maximum of four randomly selected samples. Panelists scored the attributes on a semi-structured 100 mm scale, with the left end representing the lowest intensity (score = 0) and the right end representing the highest intensity (score = 10). The references for the extremes and intermediate values of the scale were adapted from Hongsoongnern and Chambers (2008).

2.4 Statistical analyses

Within each cropping system, data were analyzed using an ANOVA considering the main effects genotype and grafting, and the interaction genotype × grafting (Gxgr). For the agronomic traits, the block effect was added to the linear model. Sensory panel ratings were analyzed using the linear model $Y_{ijkl} = \mu + P_i + G_j + gr_k + G_j x gr_k + P_i x gr_k + P_i x G_j + P_i x G_j x gr_k + \varepsilon_{ijkl}$, where Y_{ijkl} is the trait measured, μ is the overall mean, P_i is the effect resulting from the ith pane list, G_j is the effect resulting from the jth genotype, gr_k is the effect resulting from the grafting treatment, and ε_{ijkl} is the residual. G, gr, and P were treated as fixed factors. For significant factors, means were separated by least significant difference (LSD) tests at $p < 0.05$. The *proc glm* procedure of the SAS statistical package v.8 (SAS Institute Inc. 1999) was used for all analyses.

3 Results

3.1 Genotypes and panelists

Under conventional management, significant differences between varieties were found in 15 of the 16 traits recorded (Tables 1, 2, 3). Under organic management, significant differences were found in 12 of the 16 traits recorded (Tables 1, 2, 3). In general, the three genotypes were significantly different on most traits, although the landraces had similar scores for some traits. The panelist factor was significant for 9 of the 10 sensory traits in both the conventional and organic experiments, but the interaction with the panelist factor was significant only for the trait pericarp mealiness (Table 1). The block effect, considered in the agronomic traits, was significant only for the trait BER in conventional management and for yield in organic management (Table 3). In conventional management, 6 of 15 possible interactions with block were significant; by contrast, in organic management, none of the interactions with block were significant.

3.2 Taste and texture sensory traits

Sensory panel ratings revealed a consistent effect of grafting on taste-related traits in both management systems, with few significant Gxgr interactions (Table 1). In the conventional system, grafting reduced sweetness (27%), acidity (8%, only significant at $p < 0.10$), and taste intensity (19%). In the organic management system, grafting reduced sweetness (16%), acidity (16%), and taste intensity (21%). The significant interaction Gxgr in sweetness and taste intensity in conventional management was attributable to the 'Egara' genotype's insensitivity to grafting with respect to these two attributes.

Table 1 Significance of the ANOVA and comparison between mean values of the different levels for the sensory traits recorded by the panel in each management system

Treatment	Sweetness		Acidity		Taste intensity		Pericarp mealiness		Skin perceptibility	
Conventional										
Grafted	3.6	b	4.3	a	3.9	b	2.8	a	5.5	b
Non-grafted	4.9	a	4.7	a	4.8	a	2.7	a	6.4	a
Sig gr	***		ns		**		ns		**	
‘Egara’	4.7	a	6.1	a	4.7	a	3.7	a	7.9	a
‘Mando’	3.1	b	3.6	b	3.9	a	2.2	b	5.0	b
‘Montgri’	5.1	a	3.7	b	4.3	a	2.4	b	4.9	b
Sig G	***		***		ns		***		***	
‘Egara’/grafted	4.7^{z}	a	6.0	a	4.6^{z}	a	3.6	a	7.7	a
‘Egara’/non-grafted	4.7	a	6.1	a	4.8	a	3.9	a	8.0	a
‘Mando’/grafted	2.1	b	3.6	a	3.6	b	2.4	a	4.4	b
‘Mando’/non-grafted	4.1	a	3.6	a	4.2	a	2.0	a	5.7	a
‘Montgri’/grafted	4.1	b	3.2	a	3.1	b	2.5	a	4.4	b
‘Montgri’/non-grafted	6.1	a	4.2	a	5.6	a	2.3	a	5.4	a
Sig Gxgr	**		ns		*		ns		ns	
Sig P	***		***		ns		***		**	
Sig G*P	ns		ns		ns		**		ns	
Sig gr*P	ns		ns		ns		ns		ns	
Sig Gxgr*P	ns		ns		ns		ns		ns	
Organic										
Grafted	3.7	b	5.1	b	4.4	b	2.9	a	5.2	a
Non-grafted	4.4	a	6.1	a	5.6	a	2.5	a	6.0	a
Sig gr	*		**		*		ns		ns	
‘Egara’	5.6	a	5.8		5.8	a	4.2	a	7.3	a
‘Mando’	3.6	b	5.6		5.2	ab	1.9	b	5.1	b
‘Montgri’	3.2	b	5.6		4.0	b	2.0	b	4.4	b
Sig G	***		ns		*		***		**	
‘Egara’/grafted	5.1	b	5.8	a	5.3	b	4.3	a	7.0	a
‘Egara’/non-grafted	6.0	a	5.8	a	6.3	a	4.2	a	7.7	a
‘Mando’/grafted	3.0	b	5.0	b	4.4	b	1.8	a	5.0	a
‘Mando’/non-grafted	4.2	a	6.1	a	6.0	a	1.9	a	5.2	a
‘Montgri’/grafted	2.8	b	4.7	b	3.5	b	2.5	a	3.6	a
‘Montgri’/non-grafted	3.5	a	6.4	a	4.5	a	1.5	a	5.1	a
Sig Gxgr	ns		ns		ns		ns		ns	
Sig P	**		***		*		***		**	
Sig G*P	ns		ns		ns		*		ns	
Sig gr*P	ns		ns		ns		ns		ns	
Sig Gxgr*P	ns		ns		ns		ns		ns	

Values of treatment, genotype, or pair genotype-grafting/genotype-no grafting, followed by the same letter in a trait and management system are not significantly different at $p < 0.05$

G: genotype effect; gr: grafting effect; P: panelist effect. Sig: significant effects in the ANOVA are marked by *$p < 0.5$; **$p < 0.01$; ***$p < 0.001$; and ns $p > 0.05$

^{z}Combination mainly responsible for the interaction Gxgr for a trait within a management system

With regard to texture-related traits, grafting reduced skin perceptibility by 14% in the conventional management system, but had no significant effect in the organic management system. Conversely, the grafting effect on mealiness was not significant in either management system. No Gxgr interactions were significant for any texture-related traits.

Table 2 Significance of the ANOVA and comparison between mean values of the different levels for the visual sensory (morphologic) traits and soluble solids content within each management system

Treatment	Fruit weight (g)		Locular relative content (%)		Width (cm)		Length (cm)		Pericarp thickness (%)		SSC	
Conventional												
Grafted	163.5	a	16.1	a	8.2	a	6.1	a	16.1	b	6.2	a
Non-grafted	151.4	b	17.2	a	7.2	b	5.5	b	18.7	a	6.2	a
Sig gr	**		ns		***		***		***		ns	
'Egara'	135.7	c	21.7	a	6.7	c	4.64	c	19.0	a	6.9	a
'Mando'	341.03	a	14.4	b	9.4	a	7.08	a	14.2	b	5.5	c
'Montgri'	150.2	b	13.6	b	7.4	b	5.8	b	18.3	a	6.1	b
Sig G	***		***		***		***		***		***	
'Egara'/grafted	123.9^{z}	b	21.7	a	6.7	a	4.7	a	18.2	a	7.4^{z}	a
'Egara'/non-grafted	159.8	a	21.6	a	6.6	a	4.6	a	19.9	a	6.5	b
'Mando'/grafted	357.0	a	14.0	a	10.2^{z}	a	7.5^{z}	a	14.2	a	5.4	a
'Mando'/non-grafted	297.1	b	14.9	a	8.3	b	6.5	b	14.3	a	5.6	a
'Montgri'/grafted	164.1	a	12.6	a	7.7	a	5.9	a	15.9^{z}	b	5.8	b
'Montgri'/non-grafted	125.7	b	14.5	a	7.0	b	5.7	a	20.8	a	6.4	a
Sig Gxgr	***		ns		***		**		***		***	
Organic												
Grafted	311.1	a	12.3	a	8.9	a	6.8	a	22.3	a	4.1	b
Non-grafted	289.9	b	12.6	a	9.3	a	7.1	a	20.1	b	4.3	a
Sig gr	**		ns		ns		ns		***		*	
'Egara'	256.6	c	16.4	a	8.9	b	6.5	c	23.7	a	4.1	a
'Mando'	434.0	a	9.5	c	10.1	a	7.0	b	20.0	b	4.1	a
'Montgri'	280.9	b	11.5	b	8.5	b	7.5	a	19.1	b	4.2	a
Sig G	***		***		***		***		***		ns	
'Egara'/grafted	268.1	a	16.1	a	8.7	a	6.3	a	24.3	a	4.1	a
'Egara'/non-grafted	250.1	a	16.7	a	9.2	a	6.7	a	23.2	a	4.2	a
'Mando'/grafted	472.2	a	10.1	a	10.2	a	6.9	a	24.9^{z}	a	3.8^{z}	b
'Mando'/non-grafted	406.1	b	8.8	a	10	a	7.0	a	16.0	b	4.5	a
'Montgri'/grafted	264.2^{z}	a	10.7	a	8.2	a	7.3	a	19.2	a	4.2	a
'Montgri'/non-grafted	291.4	a	12.4	a	8.8	a	7.7	a	19.1	a	4.1	a
Sig Gxgr	**		ns		ns		ns		***		**	

Values of treatment, genotype or pair genotype-grafting/genotype-no grafting followed by the same letter in a trait and management system are not significantly different at $p < 0.05$

G: genotype effect; gr: grafting effect. Sig: significant effects in the ANOVA are marked by *$p < 0.5$; **$p < 0.01$; ***$p < 0.001$; and ns $p > 0.05$

^{z}Combination main responsible for the interaction Gxgr for a trait in the management system

3.3 Visual sensory traits (fruit morphology) and SSC

With respect to SSC and the 5 traits related to fruit morphology, the grafting factor was significant for 4 of the 6 in the conventional management system and 3 of the 6 in the organic system (Table 2). Except for pericarp thickness in conventional and SSC in organic management system, grafting increased the expression of the morphologic traits where significance was detected. In conventional management, the interaction Gxgr was significant for all these traits except locular relative content, whereas in organic management Gxgr was not significant for locular relative content, width, or length (Table 2). The factors responsible for the significance of the interaction Gxgr varied across the traits and management systems, showing that the effect of grafting on fruit morphology is highly dependent on the rootstock/scion combination and management system. For instance, under organic management, grafting significantly increased fruit weight in 'Mando' (grafted: 472.2 g; non-grafted: 406.1 g) but did not affect it in 'Egara' (grafted: 268.1; non-grafted: 250.1 g) or 'Montgri' (grafted: 264.2 g; non-grafted: 291.4). However, under conventional management, grafting significantly increased fruit weight in

Table 3 Significance of the ANOVA and comparison between mean values of the different levels for the agronomic traits within each management system

Treatment	Yield (kg m^{-2})		Number of fruits m^{-2}		Fruit weight heterogeneity (CV, %)		Fruit cracking (%)		BER (%)	
Conventional										
Grafted	19.8	a	121.1	a	47.5	a	10.0	a	9.5	a
Non-grafted	13.0	b	86.9	b	40.5	b	6.0	b	0.9	b
Sig gr	***		***		***		*		***	
'Egara'	17.6	a	126.3	a	36.5	b	1.8	c	5.7	ab
'Mando'	19.7	a	58.7	c	48.4	a	18.3	a	9.9	a
'Montgri'	13.2	b	91.9	b	48.9	a	10.5	b	1.8	b
Sig G	**		***		***		***		**	
'Egara'/grafted	22.9	a	186.4	a	40.7	a	3.9	a	16.6	a
'Egara'/non-grafted	14.8	b	92.9	b	34.1	b	0.6	a	0.0	b
'Mando'/grafted	23.0	a	66.0	a	54.1	a	26.0	a	14.9	a
'Mando'/non-grafted	12.9	b	44.0	a	36.9	b	2.8	b	0.0	b
'Montgri'/grafted	15.9	a	96.3^z	a	49.7^z	a	7.4^z	a	1.5^z	a
'Montgri'/non-grafted	10.9	b	88.3	a	48.3	a	13.0	a	2.0	a
Sig Gxgr	ns		***		**		*		***	
Sig B	ns		ns		ns		ns		**	
Sig G*B	ns		ns		*		*		*	
Sig gr*B	**		ns		*		ns		ns	
Sig Gxgr*B	ns		ns		ns		ns		**	
Organic										
Grafted	8.2	a	26.3	a	32.6	a	54.6	a	1.6	a
Non-grafted	6.8	b	23.5	b	31.4	a	56.3	a	0.4	a
Sig gr	**		*		ns		ns		ns	
'Egara'	7.6	a	29.7	a	22.4	b	51.2	b	0.0	a
'Mando'	6.9	a	15.8	b	36.0	a	64.8	a	0.7	a
'Montgri'	7.8	a	27.8	a	38.4	a	51.1	b	2.3	a
Sig G	ns		***		***		*		ns	
'Egara'/grafted	7.9	a	29.8	a	21.1	a	57.8^z	a	0.0	a
'Egara'/non-grafted	7.4	a	29.7	a	23.4	a	45.5	a	0.0	a
'Mando'/grafted	8.6	a	18.4	a	34.7	a	58.9	a	0.0	a
'Mando'/non-grafted	5.3	b	13.4	b	37.2	a	70.8	a	1.4	a
'Montgri'/grafted	8.0	a	29.8	a	42.4	a	46.9	a	4.9	a
'Montgri'/non-grafted	7.6	a	26.0	a	34.9	a	54.9	a	0.0	a
Sig Gxgr	ns		ns		ns		*		ns	
Sig B	*		ns		ns		ns		ns	
Sig G*B	ns		ns		ns		ns		ns	
Sig gr*B	ns		ns		ns		ns		ns	
Sig Gxgr*B	ns		ns		ns		ns		ns	

Values of treatment, genotype, or pair genotype-grafting/genotype-no grafting followed by the same letter in a trait and management system are not significantly different at $p < 0.05$

G: genotype effect; gr: grafting effect; and B: block effect. Sig: significant effects in the ANOVA are marked by *$p < 0.5$; **$p < 0.01$; ***$p < 0.001$; and ns $p > 0.05$

^{z}Combination mainly responsible for the interaction Gxgr for a trait within a management system

'Montgri' (grafted: 164.1 g; non-grafted: 125.7 g) and 'Mando' (grafted: 357.0 g; non-grafted: 297.1 g) but decreased it in 'Egara' (grafted: 123.9 g; non-grafted: 159.8 g). Most of the significant interactions Gxgr were due to the nonlinear response of 'Mando' to grafting, in both conventional and organic management.

3.4 Agronomic traits

On average, grafting increased yield significantly in both management systems: the mean increase was 21% in organic management and 50% in conventional management (Table 3). Gains in yield from grafting were linear within management systems as the interaction Gxgr was not significant in either management system. In conventional management, grafting improved yield in all the cultivars: 'Montgri' increased from 10.9 to 15.9 kg m^{-2}, 'Egara' from 14.8 to 22.9 kg m^{-2}, and 'Mando' from 12.9 to 23.0 kg m^{-2}. In organic management, grafting improved yield significantly only in 'Mando' (from 5.3 to 8.6 kg m^{-2}).

Grafting significantly increased the number of fruits per m^{-2} in both management systems: the mean increase was 12% in organic management and 39% in conventional management. The response to grafting in conventional management was not linear, and there was a Gxgr interaction, mainly due to 'Montgri''s low response to grafting (in conventional field, grafted: 96.3 fruits m^{-2}, non-grafted: 88.3 fruits m^{-2}; in organic field, grafted: 29.8 fruits m^{-2}; non-grafted: 26.0 fruits m^{-2}). The response to grafting was highest in the modern cultivar 'Egara' in conventional management, where the number of fruits increased by 108%, and was lowest in 'Egara' under organic management, where it increased only by 0.3%.

In organic management, grafting had no significant effects on the remaining agronomic variables (fruit-weight heterogeneity, fruit cracking, and BER); however, in the conventional experiment, grafting significantly increased fruit-weight heterogeneity, fruit cracking, and the incidence of BER. In conventional management, the interaction Gxgr was significant for these three traits, in all cases due to 'Montgri''s lack of response to grafting. In organic management, the interaction Gxgr was significant only for fruit cracking, attributable to the increase in this variable in grafted 'Egara' plants (grafted: 57.8%; non-grafted: 45.5%). Fruit cracking was unusually high in organic management, possibly due to the much higher fluctuations in soil moisture in furrow-irrigated systems.

4 Discussion

4.1 Experiment performance

The three genotypes chosen for the experiment proved to encompass a considerable amount of variation for the traits under study. Important differences were found between the modern cultivar 'Egara' and the landraces 'Mando' and 'Montgri', although many traits also differed between the landraces (Tables 1, 2, 3). The different response of each genotype to conventional and organic management increased the opportunities for evaluating the grafting effect.

The significance of the panelist effect is quite common in sensory experiments and is related to slight differences in the reference values that judges learn (Romano et al. 2008). This effect is considered in the model and can be separated from the other effects that are under analysis. As an interaction with the panelist effect occurred only in 2 of 30 interactions considering both conventional and organic management (Table 1), the panel's discriminatory ability was very high.

The block effect was present in only two traits (yield under organic management and BER under conventional management), but some of its interactions in conventional management were also significant. Unfortunately, it is very difficult to interpret interactions of this type and to attribute them to specific biological*environmental factors. Nevertheless, the presence of the block effect in the model helps us understand the other main effects.

4.2 Grafting effects

Grafting decreased sweetness and taste intensity in conventional management and decreased sweetness, acidity, and taste intensity in organic management (Table 1). Many European consumers prefer high levels of these attributes (Causse et al. 2010), so we can conclude that grafting onto 'Beaufort' had a negative impact on the sensory profile of the varieties under study. The only positive sensory effect was a decrease in skin perceptibility in conventional management. Few studies have used trained or consumer panels to assess the impact of grafting on tomato sensory profiles. Our results agree with those obtained by Barrett et al. (2012), who reported that grafting the 'Brandywine' heirloom onto 'Multifort' and 'Survivor' rootstocks had negative effects on acceptability and tomato flavor descriptors assessed by a consumer test. However, when these authors repeated the experiment in a second year, consumer ratings did not differ between treatments. By contrast, in another study that used a trained panel to assess the effect of two widely used rootstocks on 'Cuore di Bue' landrace, Di Gioia et al. (2010) reported grafting had no effect on 6 sensory attributes, and panelists actually expressed a preference for tomatoes from plants grafted onto 'Maxifort'.

The magnitude of the loss of sensory value attributable to grafting differed among the three genotypes studied. In the conventional management system, whereas no significant losses of sensory value were appreciated in the commercial cultivar 'Egara', the sensory profile of both landraces worsened, except for the trait skin perception, which improved. In the organic management system, the pattern is similar, but like both landraces, 'Egara' also lost sweetness and taste intensity. The magnitude of the negative effects varied slightly in function of the genotype and management system.

In our study, grafting did not have a consistent effect on SSC in either conventional or organic management (Table 2). In the literature, the results vary widely, with some authors reporting an increase (Fernandez-Garcia et al. 2004; Flores et al. 2010; Rahmatian et al. 2014; Stazi et al. 2016), others a decrease (Schwarz et al. 2013; Riga 2015), and others no effect (Di Gioia et al. 2010; Barrett et al. 2012). In any case, SSC proved to be a poor estimator for sweetness across our experiment, as the correlation coefficient between these two traits was $r = 0.6$ in conventional and $r = 0.3$ in organic management, both significant ($p < 0.05$). Previous studies show that sensory sweetness is a complex trait controlled not only by sugars, but also by their interaction with acids and volatiles (Baldwin et al. 2008). So, it seems clear that a panel approach is needed for a fine evaluation of sweetness.

In the past decade, grafting has emerged as a promising technique to increase yield, improve resistance to abiotic stress, and protect tomato crops against soil-borne diseases. These benefits have led tomato growers to adopt grafting, even in the absence of soil-borne diseases or abiotic stress (as in our experimental fields, where no virus symptoms or fungal wilting were observed). In these situations, grafting can improve marketable yields by increasing the photosynthetic area and other yield-related components (He et al. 2009). In our experiment, grafting greatly increased yields in both conventional (by 50%) and organic management (by 21%). In both management systems, much of this yield increase was due to an increase in the number of fruits per m^{-2}, but increased fruit weight due to increased fruit density and/or size was also important. Our results are similar to those of other studies. For instance, Di Gioia et al. (2010) reported that mean fruit yield increased from 20 to 28% in a study comparing the effect of ‘Beaufort’ and ‘Maxifort’ rootstocks on the Italian landrace ‘Cuore di Bue’ in an environment similar to that of our conventional management system (greenhouse and conventional/high-input cropping system). However, we also found that in conventional management grafting increased fruit cracking and BER in parallel to yield and increased fruit heterogeneity, both of which can diminish the commercial value of the fruits.

In conventional management, grafting increased yield similarly in all three genotypes; in organic management, the increase was significant only in the ‘Mando’ landrace. The effects of grafting on other agronomic traits varied widely with each combination of management system and genotype, making it very difficult to identify a different response pattern to grafting between ‘Egara’ and the landraces. In summary, grafting has a larger effect on yield in conventional management, but gains in yield must be balanced against losses to BER and fruit cracking. In both conventional and organic management, significant interactions make it difficult to discern common causal explanations.

4.3 Environmental effects

Our experimental design does not allow a comparison between the results obtained in the organic and the conventional environments. To make our results more relevant to farmers’ real approaches, we applied a different cultivation schedule in each location. This means that, for instance, differences in yield observed between conventional (mean values, grafted: 19.8 kg m^{-1}; non-grafted: 13.0 kg m^{-2}) and organic (grafted: 8.2 kg m^{-2}; non-grafted: 6.8 kg m^{-2}) environments can be attributed to different factors [mainly organic vs. conventional production, but also single- vs. double-stemmed conduction (Rahmatian et al. 2014) or furrow vs. drip-tape irrigation]. Likewise, it would not make sense to compare other variables across environments. Moreover, year-to-year and intra-cycle variation can also alter the results, so further studies are necessary to explore these environmental effects.

In conclusion, in environments free of important biotic and abiotic stresses, the sensory profile of fruits from grafted plants worsened, especially under conventional management. Furthermore, grafting resulted in changes in the appearance of the fruits that might affect consumers’ acceptance. Losses in sensory quality affected the landraces more than the improved cultivar. Grafting resulted in large gains in yields, especially in conventional management, but also increased fruit cracking and BER in conventional management. Thus, before adopting grafting, tomato landrace growers interested in selling their fruits in quality vegetable markets need to perform specific studies with different rootstock-scion combinations to ensure that yield is improved in their growing environment without a negative impact on organoleptic quality.

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