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Grafting and Plant Density Influence Tomato Production in Organic Farming System

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Abstract: The tomato is a key crop cultivated worldwide for the fresh and processing markets. Only a small percentage of the tomatoes processed by industries were produced following the guidelines of the organic farming system. Potential reasons for the limited share of organic tomato production are probably related to the lower yield obtained in organic farming in comparison with conventional farming. In this study, the use of the cherry tomato genotype 'Tomito' as a rootstock and two different plant densities (2.5 and 1.25 plant m^{-2}) were evaluated in order to improve the agronomic performances of the commercial processing tomato genotype 'H3402′ cultivated in the organic farming system. Agronomic and quality parameters were assessed at harvest time. The plant density influenced the plant biometric parameters, mass and marketable yield, and fruit health and quality. The use of a rootstock improved the marketable yield per plant (more than 59%), with the quality of the fruit decreasing the number of sunburnt fruits (−27.7%). The use of the 'Tomito' as a rootstock and a plant density of 2.5 plant m^{-2} are the better choices to achieve good performances in optimal environmental conditions. However, further studies are required to validate these results both in other environments and using different scions.

Keywords: grafting; plant density; tomato; quality; production

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1. Introduction

The tomato (*Solanum lycopersicum* L.) is an important horticultural crop cultivated for both the fresh and processing markets [1]. Italy is the leading country in Europe in tomato production with a production of ~5.2 million tons of tomatoes, of which 4.8 tons are used by processing industries [2]. In Italy, about 6% of the tomatoes processed by industries were produced following the guidelines of organic farming systems. Potential reasons for the limited share of organic tomato production are probably related to the lower yield obtained in organic farming in comparison with conventional farming and to challenges related to organic production, due, for example, to restrictions on the use of fertilizers and plant protection products [3,4].

Plant density, calculated as the number of plants per square meter, is considered an important factor that can affect tomato production [5]. An increase in plant density implies an increase in intraspecific competition among plants for resources, such as water, nutrients, and solar radiation. High plant density decreases the solar radiation intercepted by every single plant [6], leading to a suboptimal photosynthesis rate and, consequently, a reduction in the size, number, and quality of the fruit. Furthermore, high plant density impacts the canopy microclimate by increasing the relative humidity and favoring the development of pathogens [7]. Therefore, the choice of an optimal plant density allows one to manage and maximize light interception, the efficient use of resources, and the reduction in plant protection products; these are important goals that organic farmers should achieve in tomato production to optimize, at the same time, the yield and quality of the fruit [5].

Grafting is an environmentally friendly and widespread agronomic practice used to exploit the benefit of selected genotypes, used as rootstocks. Initially, grafting was applied to increase the tolerance of crops against soil pathogens [8]. Later the practice became more and more common as a means of improving tolerance against abiotic and biotic stresses, as well as to enhance the yield by increasing fruit size or number of fruits per plant and the quality of the productions of commercial genotypes used as scions [9].

We believe that grafting is a viable alternative to classic breeding, as a means of improving fruit yield and the quality of processing tomato plants when grown in an organic cropping system, allowing one to reap the benefits of the rootstock and the scion in a shorter time and at lower cost.

Grafting is considered standard practice for the production of fresh-market tomatoes, especially plants grown in greenhouse conditions [10]. On the other hand, this practice is not widespread for plant production in processing tomatoes; however, it could be a viable solution to cope with stresses difficult to manage in the open field due to the influence of several erratic factors.

At present, only a few studies have addressed grafting and plant density together to find the best agronomic practice. A recent field trial, carried out in an organic farming system, has reported that the use of the interspecific rootstock 'RT1′ increased the number of flowers and leaves per plant, the marketable yield, the number of fruits per plant, and the fruit dry weight without affecting the quality of the fruit produced by the processing tomato genotype 'TC266′ [11]. In a controlled condition experiment, the use of the cherry tomato genotype 'Tomito' as a rootstock grafted onto 'H3402′ increased the height of the plants and the leaf chlorophyll content compared to the control plants (both self-grafted and non-grafted) [9]. Cherry tomato genotypes have intermediate characteristics between wild-type and commercial genotypes [12], with high productivity [13] and a good tolerance to abiotic stresses such as salinity or nutritional deficiency [14]. For these reasons, we hypothesized that the use of a cherry tomato genotype as a rootstock could improve the performance of commercial tomato genotypes.

This study investigated the use of the cherry tomato genotype 'Tomito' as a rootstock and two different plant densities on the agronomic performance of the commercial processing tomato genotype 'H3402′ cultivated in organic farming systems. Our objective was to increase knowledge about the use of rootstocks in the production of organic processing tomatoes and to find the right plant density for the rootstock; this can increase the performance of tomato plants, making rootstocks cost-effective for processing tomatoes on a large scale.

2. Materials and Methods

Two open field experiments were carried out in contrasting environments on the Italian mainland, an alluvial plain characterized by a semi-continental climate vs a hill near the sea characterized by a Mediterranean climate. In 2019, a field trial was performed at the organic farm 'Coop. Agricola La Collina' in Reggio Emilia in northern Italy (44°41′10.3″ N 10°34′20.5″ E; 65 m above sea level.) (Figure 1). In 2022, a second field trial was performed at the University of Salerno in Fisciano in southern Italy (40°46′30.2″ N 14°47′44.3″ E; 320 m above sea level). The experimental design was a randomized block with 3 replications, 3 treatments (non-grafted plants, self-grafted plants, and grafted plants), and 2 plant densities: 2.5 plants m^2 (1.6 m between each row and 25 cm between the plants in the row) and 1.25 plants m^2 (1.6 m between each row and 50 cm between the plants in the row). Two border rows were planted for each plot. The plots were 12 m^2 (1.6 × 7.5 m) and 24 m^2 (1.6 × 15 m) for the densities of 2.5 and 1.25, respectively, and contained 30 plants. The tomato genotype 'H3402′ (Heinz, Pittsburgh, PA, USA), selected as a scion, was grafted onto the genotype 'Tomito' (ISI Sementi SpA, Fidenza, Italy), a cherry type used as the rootstock in this study. Both genotypes are commonly used in Italy for processing tomato production. As reported in Caradonia et al. [9], the two hybrids have a determinate growth habit and a good vigor and potential yield.

Figure 1. Field trial in Reggio Emilia in 2019.

In both years, the grafted seedlings were produced as reported by Caradonia et al. [9]. Briefly, the seedlings were grown in plateaus (510 mm × 310 mm × 42 mm) under controlled conditions (temperatures (day/night): 25/19 °C; humidity: ~60%), and were grafted at 4 true-leaf stage using the splice grafting technique. Two weeks after the grafting, the seedlings were transplanted in the open field (on 11 May 2019 and 20 May 2022). Table 1 shows the weather conditions registered in the two locations (Reggio Emilia and Fisciano) from May to September 2019 and 2022, respectively.

Table 1. Weather conditions in Reggio Emilia and Fisciano as monthly average.

Month	Total Rainfall		Relative Humidity (%)		Minimum Temperature (°C)		Maximum Temperature (°C)	
	Reggio Emilia	Fisciano	Reggio Emilia	Fisciano	Reggio Emilia	Fisciano	Reggio Emilia	Fisciano
May	214.8	45	66	59	10.6	8.3	20.3	32
June	27.2	25	45.6	55	20	13.7	32.3	37.6
July	89.4	28	52.9	56	20.3	14.7	32.5	35
August	19.2	114	55.3	58	20.1	14.6	32.1	36.3
September	74.8	305	62.3	63	15.3	10.9	26.1	31

In Reggio Emilia, the soil was a silty loam with 1.9% organic matter and pH 7.7 (in H_2O). The nutrient content was 1.5‰ total N (Kjeldahl method), 60 mg kg^{-1} available P (Olsen method), and 179.9 mg kg^{-1} exchangeable K (ammonium acetate). The crop rotation performed was "alfalfa (four years)—bread wheat (one crop cycle)".

In Fisciano, the soil was a sandy loam with 2.8% organic matter and pH 7.9 (in H_2O). The nutrient content was 1.0‰ total N (Kjeldahl method), 18 mg kg^{-1} available P (Olsen method), and 234 mg kg^{-1} exchangeable K (ammonium acetate). The crop rotation performed was "fallow (one year)—bread wheat (one crop cycle)".

In both years, fermented cow manure was applied (40 t ha−1) before the soil plowing. In each plot, 100% of the evapotranspiration of the crop was restored when 40% of the total available water was depleted. A total of 211.2 mm and 350 mm of irrigation water were applied in 2019 and 2022, respectively, using the rain gun sprinkler irrigation system. The weed control was made manually, and pests and pathogens were controlled by the plant protection products allowed by Regulation EU 2018/848 on organic production (Supplementary Table S1).

A single harvest was carried out at each field on 14 September 2019 and 23 September 2022, when ~85% of the fruits were ripe. Biometric (collar diameter, plant height, branch length, and number of leaves per plant), mass (root dry weight, above ground dry weight, and marketable yield), and qualitative (number of sunburnt fruits, green fruits, and fruits infected by *Alternaria* spp.), the average weight of the fruits, the pulp color, and the solid soluble content Brix, Brix yield, and pH) parameters were recorded for six plants per treatment.

The root and the aboveground organs were oven-dried at 65 °C until they reached a constant weight. The pulp color was assessed as the ratio of chromaticity indices "a*" (redness) over "b*" (yellowness) using a Gardner XL-23 tristimulus colorimeter (Gardner Laboratory Inc., Bethesda, MD, USA). For the fruit quality, 1 kg of collected fruits per harvest plot was ground and homogenized. The refractometer HI 96814 (Hanna, Italy) was used for determining the solid soluble content, and the pH meter pH 8+ DHS (XS instruments, Italy) was used to determine if the pH. Brix yield was calculated as reported in [15].

The data were subjected to analysis of variance (ANOVA), and the means were separated through the Duncan's test ($p < 0.05$) using the statistical program GenStat 17th (VSN International, Hemel, Hempstead, UK).

3. Results

Significant interactions were found between plant density and grafting for many of the evaluated parameters (Tables 2–7); the exceptions were marketable yield per plant, number of infected fruits, pulp color (as a b ratio), Brix yield, and pH of tomato juice in the experiment carried out in Reggio Emilia, and marketable yield per plant, number of sunburnt fruits and infected fruits, Brix yield, and pH of tomato juice in the experiment carried out in Fisciano.

Table 2. Effects of grafting and plant density on plant biometric parameters and dry matter in 2019 in Reggio Emilia.

		Diameter of Root Collar (cm)		Plant Height (cm)		Branch Length (cm)		Number of Leaves Plant^{-1}		Root Dry Weight (g)		Above Ground Dry Weight (g)	
Treatment	**H**	1.4 ± 0.12	c	33.2 ± 6.47	b	98.5 ± 21.91		64.4 ± 9.26	c	87.3 ± 11.74	b	483.3 ± 56.43	c
	H/H	1.8 ± 0.17	b	33.2 ± 1.08	b	106.0 ± 22.22		82.0 ± 17.21	b	112.5 ± 45.48	a	621.2 ± 82.55	a
	H/T	1.9 ± 0.22	a	38.3 ± 4.23	a	99.6 ± 8.62		87.9 ± 16.54	a	74.5 ± 21.37	c	585.0 ± 159.21	b
***p* value**		<0.001		<0.001		n.s.		<0.001		<0.001		<0.001	
Plant density (plant number m^{-2})	**2.50**	1.5 + 0.19	b	31.4 ± 3.32	b	83.5 ± 3.79	b	65.1 ± 7.41	b	74.7 ± 18.84	b	473.1 ± 56.23	b
	1.25	1.8 ± 0.27	a	38.4 ± 3.62	a	115.6 ± 10.61	a	91.2 ± 13.98	a	108.2 ± 35.17	a	653.2 ± 91.33	a
***p* value**		<0.001		<0.001		<0.001		<0.001		<0.001		<0.001	
Treatment × Plant density													
H	**2.50**	1.3 ± 0.03	e	27.3 ± 1.60	e	78.5 ± 0.50	e	56.0 ± 1.00	e	98.0 ± 1.00	b	432.7 ± 11.50	d
H/H	**2.50**	1.6 ± 0.02	c	32.5 ± 0.50	d	85.5 ± 0.50	d	66.3 ± 1.52	d	71.0 ± 1.00	e	546.3 ± 8.08	c
H/T	**2.50**	1.7 ± 0.01	c	34.5 ± 0.50	c	86.5 ± 0.50	d	72.8 ± 0.76	c	55.0 ± 1.00	f	440.3 ± 18.55	d
H	**1.25**	1.5 ± 0.03	d	39.0 ± 0.50	b	118.5 ± 0.50	b	72.8 ± 1.04	c	76.7 ± 1.52	d	534.0 ± 11.35	c
H/H	**1.25**	1.9 ± 0.04	b	34.0 ± 1.00	cd	126.1 ± 0.92	a	97.7 ± 1.52	b	154.0 ± 2.00	a	696.0 ± 13.07	b
H/T	**1.25**	2.1 ± 0.10	a	42.2 ± 0.76	a	102.7 ± 1.25	c	103.0 ± 1.00	a	94.0 ± 1.00	c	729.7 ± 15.50	a
***p* value**		0.03		<0.001		0.001		<0.001		<0.001		<0.001	

The data are reported as mean. Means followed by the different letters are statistically significant at $p < 0.05$; n.s., not significant. H = non-grafted plant, H/H = self-grafted plants, and H/T = grafted plants.

Table 3. Effects of grafting and plant density on biometric parameter and dry matter in 2022 in Fisciano.

		Diameter of Root Collar (cm)		Plant Height (cm)		Branch Length (cm)		Number of Leaves Plant^{-1}		Root Dry Weight (g)		Above Ground Dry Weight (g)	
Treatment	**H**	1.4 ± 0.14	c	35.5 ± 8.26	b	102.5 ± 22.52	b	66.7 ± 9.56	c	95.7 ± 18.34	a	512.8 ± 63.75	c
	H/H	1.9 ± 0.37	b	35.5 ± 1.04	b	110.5 ± 24.68	a	80.5 ± 14.15	b	97.7 ± 21.41	a	661.5 ± 105.66	a
	H/T	2.1 ± 0.32	a	40.5 ± 4.59	a	97.6 ± 9.61	c	91.3 ± 14.50	a	71.7 ± 14.04	b	574.7 ± 183.70	b
***p* value**		<0.001		<0.001		<0.001		<0.001		<0.001		<0.001	
Plant density (plant number m^{-2})	**2.50**	1.5 ± 0.42	b	33.6 ± 4.60	b	86.3 ± 11.83	b	68.0 ± 12.84	b	77.1 ± 27.13	b	476.1 ± 90.56	b
	1.25	2.0 ± 0.23	a	40.8 ± 4.30	a	120.8 ± 3.39	a	91.0 ± 8.99	a	99.6 ± 26.46	a	689.9 ± 26.46	a
***p* value**		<0.001		<0.001		<0.001		<0.001		<0.001		<0.001	
Treatment × Plant density													
H	**2.50**	1.3 ± 0.10	e	28.0 ± 1.00	c	82.0 ± 1.00	e	58.0 ± 1.00	e	112.3 ± 2.52	b	455.0 ± 4.0	c
H/H	**2.50**	1.5 ± 0.06	d	36.0 ± 1.00	b	88.0 ± 1.00	d	67.7 ± 1.53	d	60.0 ± 1.00	e	566.0 ± 11.14	b
H/T	**2.50**	1.8 ± 0.08	c	36.7 ± 1.53	b	89.0 ± 1.00	d	78.3 ± 3.06	c	59.0 ± 1.00	e	407.3 ± 15.53	d
H	**1.25**	1.5 ± 0.10	d	43.0 ± 1.00	a	123.0 ± 2.65	b	75.3 ± 1.53	c	79.0 ± 1.00	d	570.7 ± 10.50	b
H/H	**1.25**	2.2 ± 0.10	b	35.0 ± 1.00	b	133.0 ± 2.00	a	93.3 ± 2.08	b	135.0 ± 5.51	a	757.0 ± 20.66	a
H/T	**1.25**	2.4 ± 0.10	a	44.3 ± 2.52	a	106.3 ± 2.08	c	104.3 ± 3.06	a	84.3 ± 3.51	c	742.0 ± 10.82	a
***p* value**		0.002		<0.001		<0.001		0.007		<0.001		<0.001	

The data are reported as mean ± standard deviations. Means followed by the different letters are statistically significant at $p < 0.05$; n.s., not significant. H = non-grafted plant, H/H = self-grafted plants, and H/T = grafted plants.

Table 4. Effects of grafting and plant density on marketable yield and fruit health in 2019 in Reggio Emilia.

		Marketable Yield Plant^{-1} (kg)		Marketable Yield (t ha^{-1})		Sunburnt Fruit (Number Plant^{-1})		Green Fruits Plant^{-1} (g)		Infected Fruit (Number Plant^{-1})	
Treatment	**H**	2.5 ± 0.18	c	46.1 ± 14.14	c	3.5 ± 1.18	a	56.5 ± 7.71	c	5.2 ± 3.09	
	H/H	3.9 ± 0.12	b	71.7 ± 24.49	b	1.4 ± 0.49	b	104.5 ± 6.97	a	4.9 ± 2.34	
	H/T	4.2 ± 0.18	a	77.7 ± 25.61	a	0.3 ± 0.51	c	72.3 ± 5.46	b	6.1 ± 2.24	
***p* value**		<0.001		<0.001		<0.001		<0.001		n.s.	
Plant density (plant number m^{-2})	**2.50**	3.4 ± 0.78	b	84.7 ± 19.63	a	2.1 ± 1.94	a	78.4 ± 18.07		3.2 ± 0.89	b
	1.25	3.6 ± 0.76	a	46.0 ± 9.61	b	1.4 ± 1.04	b	77.1 ± 25.61		7.7 ± 1.00	a
***p* value**		<0.001		<0.001		0.03		n.s.		<0.001	
Treatment × Plant density											
H	**2.50**	2.4 ± 0.08		58.9 ± 2.00	c	4.5 ± 0.50	a	63.0 ± 4.58	c	2.5 ± 0.50	
H/H	**2.50**	3.8 ± 0.10		94.0 ± 2.53	b	1.3 ± 0.57	cd	101.3 ± 3.05	a	2.9 ± 0.36	
H/T	**2.50**	4.0 ± 0.06		101.1 ± 1.50	a	0.3 ± 0.57	e	71.0 ± 7.00	bc	4.1 ± 0.76	
H	**1.25**	2.7 ± 0.11		33.2 ± 1.44	f	2.5 ± 0.50	b	50.0 ± 1.00	d	8.0 ± 1.00	
H/H	**1.25**	3.9 ± 0.06		49.4 ± 0.75	e	1.5 ± 0.50	c	107.7 ± 9.07	a	7.0 ± 1.00	
H/T	**1.25**	4.3 ± 0.10		54.4 ± 1.25	d	0.3 ± 0.57	d	73.7 ± 4.50	b	8.0 ± 1.00	
***p* value**		n.s.		<0.001		0.008		0.024		n.s.	

The data are reported as mean ± standard deviations. Means followed by the different letters are statistically significant at $p < 0.05$; n.s., not significant. H = non-grafted plant, H/H = self-grafted plants, and H/T = grafted plants.

Table 5. Effects of grafting and plant density on marketable yield and fruit health in 2022 in Fisciano.

		Marketable Yield Plant^{-1} (kg)		Marketable Yield (t ha^{-1})		Sunburnt Fruit (Number Plant^{-1})		Green Fruits Plant^{-1} (g)		Infected Fruit (Number Plant^{-1})	
Treatment	**H**	2.8 ± 0.22	c	51.0 ± 15.60	c	2.2 ± 0.75	a	27.5 ± 2.88	b	4.0 ± 2.28	
	H/H	4.1 ± 0.31	b	75.4 ± 22.86	b	1.2 ± 0.41	b	49.2 ± 7.36	a	5.5 ± 1.38	
	H/T	4.4 ± 0.22	a	81.7 ± 26.62	a	1.0 ± 0.01	b	53.3 ± 21.01	a	5.3 ± 1.75	
***p* value**		<0.001		<0.001		<0.005		<0.001		n.s.	
Plant density (plant number m^{-2})	**2.50**	3.6 ± 0.78	b	89.1 ± 9.77	a	1.4 ± 0.73		36.7 ± 21.28		3.8 ± 1.45	b
	1.25	4.0 ± 0.74	a	49.7 ± 18.58	b	1.4 ± 0.73		50.0 ± 7.11		6.1 ± 1.48	a
***p* value**		<0.001		<0.001		n.s.		n.s.		0.002	
Treatment × Plant density											
H	**2.50**	2.6 ± 0.10		65.2 ± 2.38	c	2.0 ± 1.00		30.0 ± 1.00	c	2.0 ± 0.01	
H/H	**2.50**	3.8 ± 0.10		96.2 ± 2.50	b	1.3 ± 0.58		45.0 ± 5.00	b	5.0 ± 1.00	
H/T	**2.50**	4.2 ± 0.10		106.0 ± 2.50	a	1.0 ± 0.01		35.0 ± 5.00	c	4.3 ± 0.58	
H	**1.25**	2.9 ± 0.16		36.9 ± 2.02	e	2.3 ± 0.58		25.0 ± 5.00	c	6.0 ± 1.00	
H/H	**1.25**	4.3 ± 0.15		54.6 ± 1.91	d	1.0 ± 0.01		53.3 ± 7.64	b	6.0 ± 1.73	
H/T	**1.25**	4.6 ± 0.10		57.5 ± 1.25	d	1.0 ± 0.01		71.7 ± 9.71	a	6.3 ± 2.08	
***p* value**		n.s.		<0.001		n.s.		<0.001		n.s.	

The data are reported as mean ± standard deviations. Means followed by the different letters are statistically significant at $p < 0.05$; n.s., not significant. H = non-grafted plant, H/H = self-grafted plants, and H/T = grafted plants.

Table 6. Effects of grafting and plant density on fruit weight and pulp color and quality in 2019 in Reggio Emilia.

		a* b*$^{-1}$		Average Fruit Weight (g)		BRIX (°Bx)		BY (t ha^{-1})		pH	
Treatment	**H**	2.5 ± 0.03	a	57.0 ± 2.86	c	4.7 ± 0.38		2.2 ± 0.84	c	4.4 ± 0.07	b
	H/H	2.3 ± 0.02	c	65.1 ± 1.28	b	4.6 ± 0.31		3.3 ± 0.93	b	4.6 ± 0.15	a
	H/T	2.4 ± 0.02	b	74.5 ± 7.87	a	4.7 ± 0.44		3.6 ± 0.86	a	4.5 ± 0.09	a
***p* value**		<0.001		<0.001		n.s.		<0.001		0.008	
Plant density (plant number m^{-2})	**2.50**	2.5 ± 0.09	a	63.7 ± 3.47	b	4.6 ± 0.37	b	3.8 ± 0.64	a	4.5 ± 0.17	
	1.25	2.4 ± 0.09	b	67.3 ± 11.84	a	4.8 ± 0.33	a	2.2 ± 0.59	b	4.5 ± 0.08	
***p* value**		0.001		<0.001		0.02		<0.001		n.s.	
Treatment × Plant density											
H	**2.50**	2.5 ± 0.03		59.5 ± 0.60	d	5.1 ± 0.15	a	3.0 ± 0.19		4.3 ± 0.10	
H/H	**2.50**	2.3 ± 0.01		64.3 ± 1.10	c	4.4 ± 0.10	b	4.1 ± 0.12		4.6 ± 0.10	
H/T	**2.50**	2.4 ± 0.01		67.3 ± 0.93	b	4.3 ± 0.10	b	4.3 ± 0.03		4.5 ± 0.10	
H	**1.25**	2.5 ± 0.01		54.4 ± 0.81	e	4.4 ± 0.10	b	1.5 ± 0.08		4.4 ± 0.10	
H/H	**1.25**	2.3 ± 0.02		65.9 ± 1.04	bc	4.9 ± 0.15	a	2.4 ± 0.04		4.5 ± 0.10	
H/T	**1.25**	2.4 ± 0.01		81.6 ± 0.83	a	5.1 ± 0.10	a	2.8 ± 0.12		4.6 ± 0.10	
***p* value**		n.s.		<0.001		<0.001		n.s.		n.s.	

The data are reported as mean ± standard deviations. Means followed by the different letters are statistically significant at $p < 0.05$; n.s., not significant. H = non-grafted plant, H/H = self-grafted plants, and H/T = grafted plants. a* b*$^{-1}$ = the ratio of chromaticity indices "a*" (redness) over "b*" (yellowness); °Brix = solid soluble content in tomato juice; BY (t ha^{-1}) = Brix t ha.

Table 7. Effects of grafting and plant density on fruit weight and pulp color and quality in 2022 in Fisciano.

		a* b*$^{-1}$		Average Fruit Weight (g)		BRIX (°Bx)		BY (t ha^{-1})		pH
Treatment	**H**	2.4 ± 0.19		59.2 ± 3.31	c	5.1 ± 0.67	ab	2.7 ± 1.15	b	4.4 ± 0.05
	H/H	2.3 ± 0.16		65.3 ± 2.50	b	5.2 ± 0.10	a	4.0 ± 1.24	a	4.5 ± 0.04
	H/T	2.4 ± 0.14		74.5 ± 5.00	a	5.1 ± 0.41	b	4.1 ± 1.02	a	4.5 ± 0.06
***p* value**		n.s.		<0.001		0.05		<0.001		n.s.
Plant density (plant number m^{-2})	**2.50**	2.4 ± 0.12	a	66.3 ± 10.14		5.2 ± 0.41	a	4.6 ± 0.67	a	4.4 ± 0.045
	1.25	2.3 ± 0.16	b	66.3 ± 3.61		5.1 ± 0.47	b	2.5 ± 0.67	b	4.5 ± 0.046
***p* value**		0.025		n.s.		0.005		<0.001		n.s.
Treatment × Plant density										
H	**2.50**	2.5 ± 0.06	a	62.0 ± 1.0	d	5.7 ± 0.21	a	3.7 ± 0.27		4.4 ± 0.06
H/H	**2.50**	2.3 ± 0.21	bc	67.0 ± 1.0	c	5.3 ± 0.10	bc	5.1 ± 0.11		4.5 ± 0.06
H/T	**2.50**	2.5 ± 0.06	ab	70.0 ± 1.0	b	4.7 ± 0.10	d	5.0 ± 0.11		4.4 ± 0.03
H	**1.25**	2.2 ± 0.01	c	56.3 ± 1.53	e	4.5 ± 0.06	d	1.7 ± 0.11		4.4 ± 0.04
H/H	**1.25**	2.4 ± 0.10	abc	63.7 ± 2.52	d	5.2 ± 0.10	c	2.8 ± 0.15		4.5 ± 0.02
H/T	**1.25**	2.3 ± 0.12	bc	79.0 ± 1.00	a	5.4 ± 0.06	b	3.1 ± 0.08		4.5 ± 0.07
***p* value**		0.009		<0.001		<0.001		n.s.		n.s.

The data are reported as mean ± standard deviations. Means followed by the different letters are statistically significant at $p < 0.05$; n.s., not significant. H = non-grafted plant, H/H = self-grafted plants, and H/T = grafted plants. a* b*$^{-1}$ = the ratio of chromaticity indices "a*" (redness) over "b*" (yellowness); °Brix = solid soluble content in tomato juice; BY (t ha^{-1}) = Brix t ha.

The responses of the tomato plants to the grafting and the different plant densities were very similar over both years and locations.

Plant density influenced the biometric parameters and the plant mass. Plants transplanted with a density of 1.25 plant m^{-2} reported the highest values (from +18% to +45%) for all the biometric parameters evaluated in both locations. In Fisciano, a density of 1.25 plant m^2 got the maximum increment in aboveground dry weight values (+45%), while in Reggio Emilia it got the maximum increment in root dry weight values (+45%). The use of a rootstock improved collar diameter (~+43.2%), the height of the plants (~+15%), and the number of leaves (~+36.5%) compared to nongrafted plants in both locations. Conversely, a decrease in root dry weight values (−14% and −25%, in Reggio Emilia and in Fisciano, respectively) was found in plants grafted onto the 'Tomito' rootstock. The best combination was found in plants grafted onto the 'Tomito' genotype at 1.25 plants m^2, except for root dry weight and branch length values. Interestingly, a positive effect of the grafting technique was observed on aboveground dry weight (29% compared to nongrafted plants) (Tables 2 and 3).

Tables 4 and 5 show the effects of grafting and plant density on marketable yield and fruit health. As expected, the density of 1.25 plant m^{-2} reported the highest marketable yield per plant (+7.6% and +11.5% in Reggio Emilia and Fisciano, respectively), whereas the grafted plants transplanted with a density of 2.5 plant m^{-2} got the best performance in terms of marketable yield t ha^{-1} (+84% and +79% in Reggio Emilia and Fisciano, respectively) in both locations. Plant density played a key role in fruit health; in fact, the density of 1.25 plant m^{-2} reported the lowest number of sunburnt fruits in 2019 in Reggio Emilia, whereas the density of 2.5 plant m^{-2} showed the lowest number of infected fruits in both years (−140% and −61% in 2019 in Reggio Emilia and in 2022 in Fisciano, respectively). The use of a rootstock also affected fruit yield and health, increasing the marketable yield (+67.5% and +59%, in Reggio Emilia and Fisciano, respectively) and decreasing the number of sunburnt fruits. The grafting influenced the ripening, increasing the weight of green fruits (+54% and +44% in Reggio Emilia and in 2022 in Fisciano, respectively).

As far as fruit quality in terms of size, pulp color, and soluble solid content are concerned (Tables 6 and 7), some differences were found between the two-location trial.

Interestingly, there was an opposite trend on Brix values between the two locations in terms of plant density. In fact, these values were the highest at a density of 1.25 plant m^2 in Reggio Emilia and at a density of 2.5 plant m^2 in Fisciano. In both years, the density of 2.5 plant m^{-2} increased both the a and b ratio and the Brix yield. The use of a rootstock increased the average fruit weight (+30.6% and 25.9% in Reggio Emilia and in Fisciano, respectively) and Brix yield (+59.8 and 59.6% in Reggio Emilia and Fisciano, respectively) in both years, while a higher pH of tomato juice in the second year only was observed in the tomatoes from the grafted plants.

4. Discussion

Plant density influenced plant morphology and biomass, as well as marketable yield and the health and quality of the fruit. As reported in previous studies [16,17], the marketable yield per plant decreased with increasing plant density. In this study, the decrease in marketable yield per plant was manly linked to a decrease in the number of fruits. This observation could be easily explained by an increase in competition among the tomato plants at 2.5 plant m^{-2} for living resources like water and nutrients, space, and solar radiation. Notably, a reduced loss of fruits due to a lower number of infected tomatoes was observed at a density of 2.5 plant m^{-2}. This result could be seen to be in contrast with a finding by Patanè and Saita [18], in which the higher density decreased the number of sunburnt fruits. However, Patanè and Saita evaluated a different processing tomato genotype (Brigade) and different plant densities, 2.5 plant m^{-2} and 5 plant m^{-2}.

The effect of grafting on tomato performance, such as fruit yield and quality, was fully assessed using resistant or tolerant rootstocks under biotic or abiotic stresses [18,19]. However, few studies evaluated the use of grafting in optimal conditions. In this study, the use of the rootstock 'Tomito' influenced the morphology of genotype 'H3402′ in terms of plant height, number of leaves, and dry biomass. These results confirmed the results obtained in a previous study using the same combination of scion and rootstock, in which the grafted plants showed a reduced root dry weight and an increased plant height and number of leaves [9]. Unlike the low increment of yield in the previous experiment, in which the spread of light blight influenced the crop performance, in the present study the use of the 'Tomito' as rootstock increased the marketable yield per plant by more than 59%, confirming the good performance of the grafted plant. This outcome confirmed the ability of the 'Tomito' to improve the performances of genotype 'H4302′ under optimal weather conditions. A recent study carried out in California [20] in which several commercial rootstocks ('Shield', 'Estamino', 'Maxifort', 'V90109′, 'FusaPro') were grafted onto three commercial processing tomato genotypes ('HM 3887′, 'N 6428′, and 'SVTM 1082′) showed an increased yield by 22% on average. Such increase is much lower than that obtained in the present study using the 'Tomito' as rootstock, putatively due to improved water and/or nutrient uptake [21]; however, further studies are needed to confirm this assumption. On the contrary, our results are similar to those obtained by Moreno et al. [22], in which the use of the commercial rootstocks 'King-Kong', 'Multifort', and 'Spirit' increased both the marketable yield (+43%) and the average fruit weight (+12%) in a fresh- market tomato under optimal conditions.

Considering the reasons why the use of a rootstock increases the yield, many studies have linked the improvement in plant performance to better uptake of water and nutrients from the soil due a higher root development [23,24]. However, in the present study, this hypothesis was not confirmed since the use of the 'Tomito' as rootstock decreased the root biomass of the tomato plants. In the present study, the better performance of the grafted plants could be linked to two combined effects: an increase in the size of the fruits and an increase in the number of leaves per plant. The higher number of leaves, in fact, as well as increasing the photosynthetic area, improved the coverage of the plants with a lower occurrence of fruit sunscald.

The difference in yield (t ha^{-1}) between the nongrafted plants grown at higher density and the grafted plants grown at lower density was very similar to the study by Aergerter at al. [20] (7 and 9.5%). The authors highlighted that grafting coupled with the right plant density could reduce the cost-effectiveness of grafting and improve the processing tomato yield under organic cropping systems, reducing the yield gap in comparison with the conventional methods [3,4].

Besides yield, fruit quality is another essential aspect to consider in processing tomato production. The solid soluble content, Brix yield, pulp color, and pH of tomato juice are paramount parameters for determining the quality of different varieties and agronomic managements. In the present study, the Brix values changed between the two years, highlighting two different effects: plant density coupled with grafting and environment (e.g., weather and soil features) (Table 1). On the other hand, the plants grafted onto the 'Tomito' and the plants with a density of 2.5 plant m^{-2} showed the best performance in terms of Brix x yield (BY, t ha^{-1}), a parameter very important for evaluating the final price of tomato processing, especially when the tomatoes are being used for the production of sauce and paste. These performances were essentially due to a high yield (kg ha^{-1}) achieved by plants that were grafted and had a density of 2.5 plant m^{-2}.

Considering pulp color, tomato pastes are considered of the finest quality when the a^*/b^* ratio is greater than 1.90 [25]. In the present study, grafting reduced the a^*/b^* ratio without compromising the quality of the tomato paste, since the a/b ratio values remained over 1.90. Interestingly, in 2019 the use of grafting increased the pH tomato juice—in any case, within the range required by the canning industries—whereas in 2022 and in the previous study this parameter was not influenced by the use of a rootstock [9]. Putatively, environmental factors could have interacted with the rootstock and modified pH.

5. Conclusions

This study provided interesting information about how plant density can influence tomato plant biometric parameters and mass as well as marketable yield and fruit health and quality. The use of the genotype 'Tomito' as a rootstock can improve the marketable yield per plant and the quality of the fruit. The better choice for achieving good agronomic performance in an organic system condition is the use of the genotype 'Tomito' as a rootstock at a plant density of 2.5 plant m^{-2}. However, it would be interesting to assess different genotypes—both as rootstock and scion—to assess the suitability of this technique in all farming systems, thus offering different options to farmers of processing tomatoes in other geographical areas.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/horticulturae9060669/s1, Table S1: Active substances used during field trails.

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