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Research paper

Hybrids and allied species as potential rootstocks for eggplant: Effect of grafting on vigour, yield and overall fruit quality traits

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ABSTRACT

Grafting of fruiting vegetables is an effective technique to overcome pests and diseases in modern cropping systems and it is often used to improve yield and fruit quality. Eggplant is an important vegetable crop that benefits significantly from grafting. In this regards, the exploitation, valorization and breeding of new rootstock genotypes as possible substitute to those commonly used (*Solanum torvum* and tomato hybrids) would permit an intensive eggplant crop system in those situations where a rootstock rotation is required. In the present article, we study the effects of several potential rootstocks including both wild/allied species of eggplant [*S. torvum* (STO), *S. macrocarpon* (SMA), *S. aethiopicum* (accession SASI), *S. aethiopicum* (accession SASa2), *S. paniculatum* (jurubeba) (SPA) and *S. indicum* (SIN)] and Msa 2/2 E7 and 460 CAL. eggplant hybrids on plant vigor, yield and fruit characteristics of eggplant F_1 hybrid ('Birgah'), in two spring-summer growing seasons (2014 and 2015). SPA and the hybrids Msa 2/2 E7 and 460 CAL. displayed a high percentage of grafting success. 'Birgah' scion grafted onto the two above-mentioned rootstocks showed a notable vigour and yield. Both rootstocks did not promote any unfavorable effects on apparent fruit quality traits and overall fruit composition. Furthermore, the concentration of glycoalkaloids in the fruit remained below the recommended safety value (200 mg/100 g of dw). These results suggest that SPA and Msa 2/2 E7 and 460 CAL. eggplant hybrids might represent a potential rootstock alternative to *S. torvum*.

1. Introduction

Eggplant (*Solanum melongena* L.) is one of the most cultivated fruiting vegetable crops world-wide, and it is ranked among the top six for the amount of its production (FAOSTAT, 2014). Italy is one of the top producers of eggplant among European countries. Eggplant is mostly cultivated in southern Italy in open field during spring-summer or under unheated greenhouses for early production. In many cases, the Solanaceous cultivation has become an intensive cropping system, with the consequent disease problems and soil fatigue that affect plant growth and yield (Bletsos et al., 2003). Lack of genotypes tolerant to biotic and abiotic stresses, together with the ban of the use of methyl bromide, has led to an increasing interest in eggplant grafting (Bletsos, 2005; Davis et al., 2008a,b; King et al., 2008; Miguel et al., 2004). Eggplant benefits significantly from grafting because soilborne diseases and abiotic stresses can cause important production losses (Bletsos et al., 2003). Among the eggplant wild and allied relatives which can be exploited as potential rootstocks, *Solanum torvum* Sw., native to India (Deb, 1979), and distributed in most pantropical areas, particularly South East Asia, the Mascarene and Pacific islands and the West Indies, has been reported to overcome a wide range of soilborne pathogens (*Verticillium dahliae* Klebahn, *Ralstonia solanacearum* (Smith) Yabuuchi et al., *Fusarium oxysporum* (Schlechtend:Fr.) f. sp. *melongenae* Matuo and Ishigami, and *Meloidogyne* spp. root-knot nematodes) (Bletsos et al., 2003; Daunay, 2008; Singh and Gopalakrishnan, 1997; King et al., 2010). However, *S. torvum* use has been limited due to lack of rapid and homogeneous seed germination (Ginoux and Laterrot, 1991). In order to overcome *S. torvum* limitations, Miceli et al. (2014) have proposed the production of grafted eggplant plantlets via unrooted grafted cutting propagation technique. Other wild relatives of eggplant, which

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have been tested as potential rootstocks for grafting include: *Solanum sisymbriifolium* Lam. and *Solanum integrifolium* Poir. (=*Solanum aethiopicum* L. Aculeatum group), although poor performance in growth, development and production has been reported (Rahman et al., 2002; Yoshida et al., 2004); the scarlet eggplant (*S. aethiopicum* Gilo, Shum, or Kumba groups) and the gboma eggplant (*Solanum macrocarpon* L.), phylogenetically close to *S. melongena* (Furini and Wunder, 2004), have been also described as tolerant to *F. oxysporum* f. sp. *melongenae* and resistant to *R. solanacearum* (Cappelli et al., 1995; Daunay et al., 1991; Hébert, 1985); *S. aethiopicum* Gilo group (Hébert, 1985) has also been reported to induce resistance to root-knot nematodes; *Solanum incanum* L. has been described as resistant to *F. oxysporium* f. sp. *melongenae* (Yamakawa and Mochizuki, 1979) and tolerant to abiotic stresses such as water and thermal stress, which are important eggplant breeding goals (Daunay, 2008). Interspecific hybrids are used as rootstock to induce pathogen tolerance, plant vigor, and greater degree of rootstock-scion compatibility specially when one of the parents is from the same species of the scion (Daunay, 2008; Lee and Oda, 2003; Miguel et al., 2007; Gisbert et al., 2011). Hybrids of tomato (*Solanum lycopersicum* L.) and interspecific hybrids of *S. lycopersicum* × *S. habrochaites* S. Knapp and D.M. Spooner are also used as eggplant rootstocks (Bletsos et al., 2003; Miguel et al., 2007; King et al., 2010). However, some tomato rootstocks are moderately compatible when grafted onto eggplant (Kawaguchi et al., 2008). Consequently, without a painstaking selection, negative effects might appear (Kawaguchi et al., 2008; Leonardi and Giuffrida, 2006; Oda et al., 1996). As the demand for eggplant grafted plantlets is growing rapidly, increasing researches have focused on the effects of the rootstock/scion combinations on plant performance in terms of yield and fruit quality. In this respect, yield, apparent quality characteristics and chemical composition of the fruits from grafted plants should remain equal or improved with respect to the non-grafted plants. According to Gisbert et al. (2011), Moncada et al. (2013), Maršič et al. (2014) and Sabatino et al. (2016) grafting can influence yield and fruit quality in eggplant. Gisbert et al. (2011) found that the use of interspecific hybrid rootstocks derived from fully compatible crosses of eggplant with related species can be a valuable approach to improve eggplant production. Although *S. torvum* remains the most used eggplant rootstock, testing a panel of potential eggplant rootstocks (wild and allied species of eggplant and/or hybrids of *S. melongena*) might be very useful in sustainable intensive eggplant cropping systems. In this article, we study the influence of a group of potential rootstocks including both wild/allied species and hybrids of eggplant on plant vigor, yield and fruit quality traits of 'Birgah' F_1 eggplant hybrid.

2. Materials and methods

2.1. Plant material and nursery production

The study was carried out in 2014 and in 2015 at the experimental farm of the Department of Agricultural, Food and Forest Sciences of Palermo (SAAF) (longitude 13°19′E, latitude 38°09′N) in the northern coast of Sicily (Italy). Eggplant F_1 hybrid 'Birgah' (violet globose shape) was used as scion. Eight potential rootstocks were tested: *S. torvum* (STO), *S. macrocarpon* (SMA), *S. aethiopicum* (SASI), *S. aethiopicum* (SASa2), *S. paniculatum* (jurubeba) (SPA), *S. indicum* (SIN), 460 CAL., which is a tetraploid hybrid between *S. melongena* and *S. integrifolium* and, finally, Msa 2/2 E7 which is a double haploid line obtained from anther culture of the tetraploid backcrosses from the somatic hybrid eggplant cv Dourga(+) *S. aethiopicum* with a tetraploid plant of the eggplant line DR2 (Rizza et al., 2002; Toppino et al., 2008). Self-grafted and ungrafted controls were included.

For the production of the grafted plant material, rootstock seeds were planted in 44-cell seedling trays, under a temperature regime of 25 °C/18 °C (day/night) in a propagation greenhouse. After 20 days, seeds of the F_1 eggplant scion were planted in 104-cell trays under the same temperature regime and planting method as the rootstocks. Due to the faster germination and growth, the hybrid rootstock Msa 2/2 E7 was sown simultaneously to the F_1 hybrid scion. Trays were watered manually every day to maintain the substrate at water holding capacity. Seventy-five days after planting all seedlings had reached an adequate diameter for grafting. Grafting was carried out using the tube grafting method as described by Lee et al. (2010), but using grafting plastic clips rather than silicon tubes. The grafting involved cutting off the rootstock at a 45° angle and making a similar cut on the scion. Attention was paid to be sure that the diameters of the rootstock/scion were nearly identical so that the two exchange sites fitted perfectly. The grafting technique used was completed by attaching a plastic clip in the grafting point to ensure the correct fit and the correct amount of pressure was applied. The grafted plants were misted and maintained at a temperature of 20 °C and a humidity rate of 95% for 7 days. After 7 days, the grafted plantlets were acclimatized to the natural conditions of the greenhouse by slowly dropping the humidity (RH 70–80%) during 3 days, until they were ready for transplant.

2.2. Growing conditions

'Birgah' plants ungrafted, self-grafted, and grafted onto STO, SMA, SASI, SASa2, SPA, SIN, Msa 2/2 E7 and 460 CAL. rootstocks were transplanted on 5th May 2014 and 4th 2015 on a Typic Rhodoxeralf soil. The field trial was conducted in a sandy clay loam soil (46.5% sand, 22.3% silt, 31.2 clay) at pH 7.2. In both years, the preceding crop was cauliflower. The soil was prepared by making a medium-deep plowing (35 cm) and a reduction of the earth aggregates achieved by mechanical rotating means. The soil was mulched with a 20 μm black polyethylene (PE) film and plug plants were transplanted in single rows 100 cm apart. In row spacing was 0.50 cm (2 plants m^{-2}) and drip irrigated. During the growing period the crop received, by drip irrigation system 250 kg nitrogen ha^{-1}, 150 kg phosphorous pentoxide ha^{-1} and 250 kg potassium oxide ha^{-1}. The fertilization was calculated on the basis of theoretical uptake, expected yields and mineral elements in soil. All cultural practices recommended for eggplant cultivation in Mediterranean environment were adopted uniformly according to crop needs (Baixauli, 2001).

2.3. Weather conditions

Meteorological data (monthly air temperature, temperature deviation from the 1986–2015 average, maximum air temperature for the month and minimum temperature for the month) from May to August of 2014 and 2015 from the meteorological station of the experimental farm of the Department SAAF, University of Palermo, Italy (°C) were obtained (Table 1). In terms of temperatures, the weather during the experimental period in 2014 and 2015 was comparable to the long term average. However, the average monthly temperatures showed the

Table 1
Average monthly air temperatures, 1986–2015 temperature deviations, monthly maximum and minimum air temperatures for 2014 and 2015.

Month	Monthly air temperature (°C)	Temperature deviation from the 1986–2015	Maximun air temperature for the month (°C)	Minimum air temperature for the month (°C)
2014				
May	19.0	−0.2	23.1	16.9
June	21.6	−1.8	24.2	19.0
July	21.5	−0.5	28.5	22.8
August	27.0	0.1	31.2	24.0
2015				
May	18.7	−0.5	21.8	16.4
June	21.2	−2.2	23.5	18.6
July	21.4	−0.6	28.2	22.0
August	26.6	−0.3	30.2	23.6

highest negative deviation in June (1.8 and 2.2 °C in 2014 and 2015, respectively).

2.4. Grafting success, plant vigor, flower emission, yield, and apparent fruit quality evaluation

The grafting success was observed after two weeks from grafting and was calculated on 100 grafted seedlings for each rootstock/scion combination. Plant vigor was assessed by plant height and root collar diameter measured at 50 days after transplanting (DAT), number of leaves at 50 DAT and above-ground biomass produced at the end of fruit harvest [including total yield and vegetative part produced (weight of the plant at the end of harvests plus vegetative part removed by pruning)]. First flower emission (expressed as DAT) were also recorded.

Commercially mature fruits were harvested according to fruit dimension, colour and glossiness. Immediately after harvesting fruits were weighed. Marketable yield and number of marketable fruits were collected. Average weight of marketable fruits was calculated.

Skin fruit firmness was determined by measuring its resistance to the plunger of a digital penetrometer (Trsnc, Italy). Each fruit was punched in two opposite point of the equatorial part of the skin (using a 6 mm diameter stainless steel cylinder probe). The mean peak force was calculated in Newtons.

Skin color was measured on four replications of five fruits per rootstock/scion combination in the equatorial region of the fruits using a tristimulus Minolta Chroma meter CR-400 (Minolta Corporation, Ltd., Osaka, Japan). Fruit chromaticity was expressed in L*, a*, b* color space coordinates (CIELAB). Chroma (C*) and Hue angle (H°) were also calculated as follows: $C^* = (a^{*2} + b^{*2})^{1/2}$, $H^\circ = \arctan(b^*/a^*)$.

Apparent quality traits of eggplant fruits were assessed in four replications of ten fruits. Commercially mature fruits from ungrafted, self-grafted, and grafted onto STO, SMA, SASI, SASa2, SPA, SIN, Msa 2/2 E7 and 460 CAL. rootstocks were evaluated. Traits were measured in an arbitrary scale according to the European Eggplant Genetic Resources Network (EGGNET) descriptors (Prohens et al., 2005). These traits included fruit curvature (1 = none; 9 = U-shaped), fruit cross section (1 = circular; 9 = very irregular), fruit calyx length (1 = very short [> 10%]; 9 = very long [> 75%]), and fruit calyx prickles (0 = none; 9 = very many [> 30]). In addition to these EGGNET descriptors, seed index (0 = none; 5 = very many [> 80] seeds visible in a longitudinal fruit section) was measured, and fruit length/width ratios were calculated.

2.5. Fruit browning

The same colorimeter was used to determine the pulp lightness by measuring the L* value (0 = black and 100 = white). Fruit was cut transversely in the equatorial part, and the color of the pulp was measured quickly after being cut, and after 30 min in the central and lateral zone. Measurements obtained immediately after cutting were marked L_0, those obtained after 30 min were marked L_{30}. The oxidation potential was estimated using the Larrigaudiere et al. (1998) method with little modifications as in part suggested by Concellòn et al. (2007). The oxidation potential was expressed as $\Delta L_{30} = (L_{30}\text{-}L_0)$.

2.6. Overall composition and fruit mineral content

Sampling for the fruit quality analysis was conducted using 3 healthy and commercially mature fruits for each replication from the second and third harvest. Each sample contained the same weight of apical, equatorial and distal zone of the fruits. Qualitative fruit characteristic analyses were conducted on fruits harvested from labeled flowers (the flowers were labeled at the fruit set stage) and all fruits were harvested after 35 days from labeling (fruit commercial maturity stage).

The juice was filtered and soluble solids content (SSC) was measured using a digital refractometer (MTD-045nD, Three-In-One Enterprises Co. Ltd. Taiwan).

Fruit dry weight was obtained, with a ponderable method, through the dehydration of the sample in a heater at 80 °C for 6–8 h.

Proteins, metals, total anthocyanins, chlorogenic acid and glycoalkaloids were assessed only in 2015. The Kjeldal method was used for protein determination. In particular, a sample rate was subjected to acid-catalyzed mineralization to turn the organic nitrogen into ammoniacal nitrogen. The ammoniacal nitrogen was then distilled in an alkaline pH. The ammonia formed during this distillation was collected in a boric acid solution and determined through titrimetric dosage. The value of ammoniacal nitrogen was multiplied by 6.25.

The ash content was determined on a 5 g sample rate. The eggplant sample was weighed in a platinum capsule, calibrated at 550 °C and heated to 150 °C for 6–8 h. The sample was subsequently incinerated on a flame and then in a muffle furnace at 550 °C for 6–8 h. The ash content was obtained by quantitative determination of the residual product.

Ca, Mg, Na, K, Fe, Mn, Z and Cu were determined using atomic absorption spectroscopy following wet mineralization (Morand and Gullo, 1970). Phosphorus levels were determined using colorimetry (Fogg and Wilkinson, 1958).

Glycoalkaloids were extracted as described by Birner (1969) with some modifications. Glycoalkaloid extraction was performed from 0.5 g samples of lyophilized and powdered flesh tissue by 95% ethanol. The analyses were carried out by means of RP-HPLC according to Kuronen et al. (1999) using partially purified solasonine and solamargine as the external standard. The data were expressed as mg/100 g dw; the limit of detection was 0.03 mg100 g^{-1} of dw.

Phenolic acids were extracted and analyzed according to Stommel and Whitaker (2003) with minor modifications. A binary mobile phase gradient of methanol in 0.01% aqueous phosphoric acid was used according to this procedure: 0–15 min, linear increase from 5 to 25% methanol; 15–28 min, linear increase from 25 to 50% methanol; 28–30 min, linear increase from 50 to 100% methanol; 30–32 min, 100% methanol; 32–36 min, linear decrease from 100 to 5% methanol; 36–43 min, 5% methanol. The flow rate was 0.8 mL/min. Quantification of chlorogenic acid (CA), carried out after a RP-HPLC separation, was based on absorbance at 325 nm relative to the sesamol internal standard and an external standard of authentic CA (Sigma-Aldrich, St.Louis, MO). The results were expressed as mg100 $g^{-1}$of dw.

The extraction and the analysis of anthocyanins were carried out on 200 mg of lyophilized and powdered peel as reported in Mennella et al. (2012). Briefly, the chromatographic separations were performed at a flow rate of 0.8 mL/min and at 0.1 AUFS. Purified delphinidin-3-rutinoside (D3R, Polyphenols Laboratories AS, Sandnes, Norway) was used as external standard in RP-HPLC analyses, with a different retention time (23.9 min) compared to delphinidin-3-(*p*-coumaroyl rutinoside)-5-glucoside (nasunin), that was eluted at a longer retention time (25.8 min for *cis*-nasunin and 26.1 min for *trans*-nasunin, respectively). As for nasunin quantification, a partially purified standard was used according to Lo Scalzo et al. (2010). The results were expressed as mg100 g^{-1} of peel dw; the limit of detection was 2.00 mg100 g^{-1} of peel dw.

2.7. Experimental design and statistical analysis

The treatments were defined by a completely randomized design with four replications per treatment, each consisting of ten plants. Data were subjected to a two-way ANOVA [year (Y) x rootstock (R)]. For proteins, metals, total anthocyanins, chlorogenic acid and glycoalkaloids, which were determined only in 2015, a one-way ANOVA was performed. Mean separation was assessed by Tukey HSD test. Percentage data were subjected to arcsin transformation before ANOVA analysis [$Ø = \arcsin(p/100)^{1/2}$]. All the statistical analysis were

Table 2
Effects of year and different eggplant rootstocks on biological parameters of 'Birgah' eggplant scion.

Treatments	Grafting success (%)		Plant height 50 DAT (cm)		Root collar 50 DAT (mm)		No. leaves 50 DAT (No.)		Aboveground biomass (kg)		First flower emission (DAT)	
Year												
2014	94.1	a	44.0	a	11.2	a	19.6	a	3.9	a	54.0	a
2015	93.8	a	44.4	a	11.3	a	19.6	a	4.0	a	53.0	a
Rootstock												
'Birgah' ungrafted	–		41.2	d	11.1	bc	15.4	d	3.9	bcd	53.0	cd
STO	99.3	a	53.3	a	13.6	a	22.6	ab	4.9	a	49.4	f
'Birgah' self-grafted	99.8	a	46.6	bc	11.4	abc	22.8	ab	4.5	ab	58.9	a
Msa 2/2 E7	99.3	a	50.8	ab	10.4	c	21.2	abc	4.2	abc	50.9	e
460 CAL.	92.6	cd	38.3	d	10.4	c	18.2	bc	4.1	bc	52.9	cd
SMA	89.6	d	47.7	abc	12.3	abc	23.0	ab	4.1	abc	58.0	a
SASI	94.5	bc	46.3	bc	12.8	ab	25.6	a	3.2	d	56.0	b
SASa2	89.4	d	27.9	e	7.1	d	11.1	d	4.0	bcd	53.4	cd
SPA	98.3	ab	45.8	bc	11.1	bc	16.7	bcd	3.6	cd	51.0	e
SIN	82.6	e	44.6	bcd	12.3	abc	19.1	bc	3.3	d	51.9	de
Significance												
Rootstock (R)	***		***		***		***		***		***	
Year (Y)	NS		NS		NS		NS		NS		NS	
R x Y	NS		NS		NS		NS		NS		NS	

Data within a column followed by the same letter are not significantly different at $p \leq 0.05$ according to Tukey HSD Test. The significance is designated by asterisks as follows: *, statistically significant differences at *p*-value below 0.05; **, statistically significant differences at *p*-value below 0.01; ***, Statistically significant differences at *p*-value below 0.001; NS = not significant.
STO = *S. torvum*; SMA = *S. macrocarpon*; SASI = *S. aethiopicum* (S. indonesia); SASa2 = *S. aethiopicum* (Sa2); SPA = *S. paniculatum* (Jurubeba); SIN = *S. indicum*; Msa 2/2 E7 = double haploid line obtained from anther culture of the tetraploid backcrosses from the somatic hybrid eggplant cv Dourga(+) *S. aethiopicum* with a tetraploid plant of the eggplant line DR2; 460 CAL. = tetraploid hybrid between *S. melongena* and *S. integrifolium*.
DAT = days after transplanting.

performed using SPSS software version 14.0 (StatSoft, Inc., Chicago, USA).

3. Results

3.1. Grafting success, plant vigor and first flower emission

Regardless of the rootstock, year did not significantly affect grafting success, plant vigor and first flower emission (Table 2). Conversely, rootstock significantly affected the above mentioned plant parameters. The highest grafting success was obtained from self-grafted plants and from plants grafted onto STO, Msa 2/2 E7 and SPA rootstocks (99.8, 99.3, 99.3 and 98.3%, respectively) (Table 2). The lowest grafting success was obtained from plants grafted onto SIN rootstock (82.6%). No significant interaction was found between Y and R in terms of grafting success (Table 2).

Rootstock significantly affected plant height at 50 DAT (Table 2). When the scion was grafted onto STO, rootstock displayed the highest plant height (53.3 cm) which was not statistically different from 'Birgah'/Msa 2/2 E7; conversely, 'Birgah'/460 CAL., although had the same height (38.3 cm) was significantly shorter than 'Birgah'/STO. The lowest plant height was found in the 'Birgah'/SASa2 scion/rootstock combination (27.9 cm). ANOVA for plant height at 50 DAT did not show a significant interaction (Y x R) (Table 2).

Rootstock significantly influenced root collar diameter at 50 DAT (Table 2). The highest root collar diameter was displayed by STO rootstock grafted plants (13.6 mm) (Table 2). However, no significant differences were found among plants grafted onto STO rootstock (13.3 mm), self-grafted and plants grafted onto SASI, 460 CAL., SMAand SIN. The lowest root collar diameter at 50 DAT was obtained by SASa2 rootstock grafted plants (7.1 mm). No significant interaction was found between Y and R (Table 2).

SASI rootstock revealed the highest number of leaves at 50 DAT (25.6), whereas, the lowest value was obtained by SASa2 rootstock grafted plants (11.1) (Table 2). ANOVA showed no significant interaction (Y x R) (Table 2).

STO rootstock grafted plants revealed the highest aboveground biomass produced (4.9) followed by self-grafted plants and plants grafted onto Msa 2/2 E7 (4.5 and 4.2 kg, respectively). The lowest value in terms of aboveground biomass produced was obtained by SASI and SIN rootstock grafted plants (3.2 and 3.3 kg, respectively) (Table 2). No significant interaction Y x R was found (Table 2).

As regards the first flower emission date (Table 2), plants grafted onto STO rootstock gave the shortest time of first flower emission (49.4 DAT). However, no significant differences were found between Msa 2/2 E7 and SPA grafted plants (50.9 and 51.0 DAT, respectively). 'Birgah' self-grafted and 'Birgah'/SMA revealed the longest first flower emission time (58.9 and 58.0 DAT, respectively) (Table 2). ANOVA showed no significant interaction (Y x R) (Table 2).

3.2. Yield

Irrespective of the rootstock, year did not significantly affect productive parameters. On the contrary, rootstock significantly affected marketable yield (Table 3). The highest yield was recorded from STO rootstock grafted plants (3.7 kg plant^{-1}) and the lowest in SASI rootstock grafted plants (2.3 kg plant^{-1}). No significant interaction was found between Y and R (Table 3).

Plants grafted onto Msa 2/2 E7 gave the highest number of marketable fruits (7.8 fruits plant^{-1}). However, no significant differences were found among self-grafted plants and ungrafted, STO, 460 CAL., SMA and SASa2 in terms of number of marketable fruits. The lowest number of marketable fruit was collected from SIN and SASI rootstock grafted plants (4.6 and 4.3 fruit plant^{-1}). ANOVA for number of marketable fruits per plant did not show a significant interaction Y x R (Table 3).

Rootstocks did not significantly affect average fruit weight (Table 3). However, plants grafted on SASa2 produced fruits with the highest average fruit weight.

3.3. Fruit physicochemical properties

Our results showed that treatments tested had no effects on fruit dry matter (Table 4). Regardless of the rootstock, year did not significantly

Table 3
Effects of year and different eggplant rootstocks on productive parameters of 'Birgah' eggplant scion.

Treatments	Marketable yield plant^{-1} (kg)		No. of marketable fruits plant^{-1} (No.)		Average fruit weight (g)	
Year						
2014	3.0	a	5.8	a	530.6	a
2015	3.0	a	6.0	a	524.5	a
Rootstock						
'Birgah' ungrafted	2.8	c	5.3	abc	525.7	a
STO	3.7	a	7.7	ab	519.8	a
'Birgah' self-grafted	3.4	ab	6.6	abc	521.5	a
Msa 2/2 E7	3.3	ab	7.8	a	465.0	a
460 CAL.	3.0	bc	5.8	abc	517.8	a
SMA	3.4	ab	6.6	abc	519.7	a
SASI	2.3	c	4.3	c	542.3	a
SASa2	3.0	bc	5.4	abc	565.6	a
SPA	2.8	bc	5.0	bc	559.0	a
SIN	2.4	c	4.6	c	538.5	a
Significance						
Rootstock (R)	***		***		NS	
Year (Y)	NS		NS		NS	
R x Y	NS		NS		NS	

Data within a column and a year followed by the same letter are not significantly different at p ≤ 0.05 according to Tukey HSD Test. The significance is designated by asterisks as follows: *, statistically significant differences at *p*-value below 0.05; **, statistically significant differences at *p*-value below 0.01; ***, statistically significant differences at *p*-value below 0.001; NS = not significant.
STO = *S. torvum*; SMA = *S. macrocarpon*; SASI = *S. aethiopicum* (S. indonesia); SASa2 = *S. aethiopicum* (Sa2); SPA = *S. paniculatum* (Jurubeba); SIN = *S. indicum*; Msa 2/2 E7 = double haploid line obtained from anther culture of the tetraploid backcrosses from the somatic hybrid eggplant cv Dourga(+) *S. aethiopicum* with a tetraploid plant of the eggplant line DR2; 460 CAL. = tetraploid hybrid between *S. melongena* and *S. integrifolium*.

Table 4
Effects of year and different eggplant rootstocks on fruit dry matter, firmness and SSC in fruits of 'Birgah' eggplant scion.

Treatments	Fruit dry matter (%)		Firmness (N)		SSC (°Brix)	
Year						
2014	5.9	a	−41.7	a	4.6	a
2015	5.8	a	−47.6	a	4.6	a
Rootstock						
'Birgah' ungrafted	6.1	a	−44.9	a	4.1	ef
STO	5.8	a	−52.9	ab	4.7	bcd
'Birgah' self-grafted	5.7	a	−32.6	a	4.5	cde
Msa 2/2 E7	5.9	a	−32.2	a	4.4	def
460 CAL.	5.8	a	−75.8	b	5.2	a
SMA	5.9	a	−45.8	a	5.0	ab
SASI	5.5	a	−44.3	a	4.0	f
SASa2	5.8	a	−28.8	a	4.9	abc
SPA	5.8	a	−42.8	a	4.1	ef
SIN	6.0	a	−46.6	a	4.7	bcd
Significance						
Rootstock (R)	NS		***		***	
Year (Y)	NS		NS		NS	
R x Y	NS		NS		NS	

Data within a column and a year followed by the same letter are not significantly different at p ≤ 0.05 according to Tukey HSD Test. The significance is designated by asterisks as follows: *, statistically significant differences at *p*-value below 0.05; **, statistically significant differences at *p*-value below 0.01; ***, statistically significant differences at *p*-value below 0.001; NS = not significant.
STO = *S. torvum*; SMA = *S. macrocarpon*; SASI = *S. aethiopicum* (S. indonesia); SASa2 = *S. aethiopicum* (Sa2); SPA = *S. paniculatum* (Jurubeba); SIN = *S. indicum*; Msa 2/2 E7 = double haploid line obtained from anther culture of the tetraploid backcrosses from the somatic hybrid eggplant cv Dourga(+) *S. aethiopicum* with a tetraploid plant of the eggplant line DR2; 460 CAL. = tetraploid hybrid between *S. melongena* and *S. integrifolium*.

Table 5
Effects of year and different eggplant rootstocks on fruit color parameters of 'Birgah' eggplant scion.

Treatments	L*		a*		b*		Chroma		Hue°	
Year										
2014	27.9	a	15.2	a	−2.1	a	15.6	a	−7.3	a
2015	28.5	a	16.4	a	−2.1	a	16.8	a	−6.9	a
Rootstock										
'Birgah' ungrafted	30.8	a	22.7	ab	−6.2	f	23.6	a	−15.2	d
STO	27.4	c	18.5	cd	−4.3	e	19.0	b	−13.1	bcd
'Birgah' self-grafted	28.2	abc	21.7	bc	−2.3	cd	21.8	ab	−6.1	bcd
Msa 2/2 E7	26.2	c	11.0	ef	−2.6	cd	11.3	cd	−13.0	bcd
460 CAL.	27.9	abc	18.2	d	−6.7	f	19.4	b	−20.0	d
SMA	28.5	abc	12.5	ef	−3.4	e	13.0	c	−15.1	cd
SASI	30.2	bc	25.1	a	2.7	a	25.3	a	6.2	a
SASa2	25.7	c	7.4	g	−1.3	cd	7.5	e	−9.7	bc
SPA	26.7	c	8.6	fg	0.9	b	8.7	de	5.4	a
SIN	30.5	ab	12.3	ef	2.1	ab	12.5	c	9.6	a
Significance										
Rootstock (R)	***		***		***		***		***	
Year (Y)	NS		NS		NS		NS		NS	
R x Y	NS		NS		NS		NS		NS	

Data within a column and a year followed by the same letter are not significantly different at p ≤ 0.05 according to Tukey HSD Test. The significance is designated by asterisks as follows: *, statistically significant differences at *p*-value below 0.05; **, statistically significant differences at *p*-value below 0.01; ***, statistically significant differences at *p*-value below 0.001; NS = not significant.
STO = *S. torvum*; SMA = *S. macrocarpon*; SASI = *S. aethiopicum* (S. indonesia); SASa2 = *S. aethiopicum* (Sa2); SPA = *S. paniculatum* (Jurubeba); SIN = *S. indicum*; Msa 2/2 E7 = double haploid line obtained from anther culture of the tetraploid backcrosses from the somatic hybrid eggplant cv Dourga(+) *S. aethiopicum* with a tetraploid plant of the eggplant line DR2; 460 CAL. = tetraploid hybrid between *S. melongena* and *S. integrifolium*.

affect firmness and SSC. Firmness was significantly affected by rootstock. 'Birgah'/460 CAL., showed the significantly highest value in terms of firmness (−75.8N) followed by 'Birgah'/STO (-52.9 N), which in turn did not significantly differ from the other rootstocks (Table 4). ANOVA for firmness did not show a significant interaction Y x R (Table 4). The rootstocks tested significantly affected SSC (Table 4). Plants grafted onto460 CAL., revealed the highest value of SSC (5.2°Brix), while, plants grafted onto SASI, showed the lowest SSC value (4.0°Brix). No significant interaction was found between Y and R for SSC (Table 4). Regardless of the rootstock, year did not significantly affect all color parameters. Conversely, ANOVA for L*, a*, b*, Chroma and Hue° colour parameters showed a significant effect of the rootstock, (Table 5). As regard L* colour coordinate, ungrafted plants and plants grafted onto SIN showed significantly higher L* values (30.8, and 30.5, respectively) than the others scion/rootstock combinations (Table 5). As concerning the a* colour coordinate, plants grafted onto SASI rootstock gave the highest value (25.1). Plants grafted onto SASa2 and SPA rootstocks showed the lowest values of a* coordinate (7.4 and 8.6, respectively) (Table 5). As regards the b* colour coordinate, fruits from plants grafted onto SASI and SIN rootstocks displayed the highest values (2.7 and 2.1, respectively) which in turn were higher than those displayed by fruits from plants grafted onto SPA (0.9). The lowest b* coordinate values were recorded in fruits from scion grafted onto 460 CAL. rootstock and ungrafted plants (-6.7 and −6.2, respectively). Regarding Chroma colour parameter, fruits from ungrafted and self-grafted 'Birgah', and from 'Birgah' grafted onto SASI rootstock showed the highest Chroma values (23.6, 21.8 and 25.3, respectively). Fruits from plants grafted onto SASa2 and SPA rootstocks gave the lowest values in terms of Chroma colour parameters (7.5 and 8.7, respectively) (Table 5). Concerning Hue° colour parameter, fruit from plants grafted onto SASI, SPA and SIN revealed the highest values (6.2, 5.4 and 9.6, respectively) which in turn showed higher values than fruits from plants grafted onto SASa2 (-9.7).The lowest Hue° values were recorded

Table 6
Effects of different eggplant rootstocks on L_0 central area, L_0 lateral area,ΔL_{30}central area and ΔL_{30} lateral area fruit of 'Birgah' eggplant scion.

Rootstock	L_0 central area		ΔL_{30} central area		L_0 lateral area		ΔL_{30} lateral area	
2015								
'Birgah' ungrafted	87.9	bc	0.75	bcd	84.9	abc	1.23	abcd
STO	88.5	abc	0.70	cd	85.4	abc	1.20	bcd
'Birgah' self-grafted	88.0	bc	0.80	abcd	85.0	abc	1.25	abcd
Msa 2/2 E7	90.3	ab	0.93	abc	87.3	ab	1.45	abc
460 CAL.	87.1	c	1.05	a	84.1	bc	1.58	a
SMA	90.7	a	0.62	d	87.9	a	0.95	d
SASI	90.6	a	1.08	a	87.8	a	1.58	a
SASa2	86.6	c	1.00	ab	83.8	c	1.55	ab
SPA	89.8	ab	0.63	d	85.1	abc	1.13	cd
SIN	86.3	c	0.80	abcd	83.4	c	1.38	abc

Data within a column and a year followed by the same letter are not significantly different at $p \leq 0.05$ according to Tukey HSD Test.
STO = *S. torvum*; SMA = *S. macrocarpon*; SASI = *S. aethiopicum* (S. indonesia); SASa2 = *S. aethiopicum* (Sa2); SPA = *S. paniculatum* (Jurubeba); SIN = *S. indicum*; Msa 2/2 E7 = double haploid line obtained from anther culture of the tetraploid backcrosses from the somatic hybrid eggplant cv Dourga(+) *S. aethiopicum* with a tetraploid plant of the eggplant line DR2; 460 CAL. = tetraploid hybrid between *S. melongena* and *S. integrifolium*.
L_0 = lightness after being cut; L_{30} = lightness after 30 min from cut; ΔL_{30} = (L_{30}-L_0).

in fruits from 'Birgah' ungrafted and grafted onto 460 CAL. (−15.2 and −20.0, respectively) (Table 5). No significant interaction was found between Y and R in terms of colour parameters.

Plants grafted onto Msa 2/2 E7, SMA, SASI and SPA, showed the highest values of L_0 central area and L_0 lateral area (90.3, 90.7, 90.6 and 89.8, respectively for L_0 central area, and 87.3, 87.9, 87.8 and 85.1, respectively for L_0 lateral area), whereas, fruits from plants grafted onto SASa2 and SIN rootstocks displayed the lowest value (86.6 and 86.3 for L_0 central area, and 81.8 and 83.4 for L_0 lateral area) (Table 6). 460 CAL. and SASI rootstocks induced the highest values in terms of ΔL_{30} central area and ΔL_{30} lateral area (1.05 and 1.08, respectively for ΔL_{30} central area, and 4.58 and 1.58, respectively for ΔL_{30} lateral area), whereas, fruits produced from plants grafted on SMA rootstock showed the lowest one (0.62 and 0.95, respectively for ΔL_{30} central area and ΔL_{30} lateral area) (Table 6).

ANOVA for total anthocyanins showed a significant effect of the rootstock (Table 7). Fruit from 'Birgah' self-grafted and 'Birgah'/SPA combination had the highest total anthocyanins content (12413.2 and 11265.6 mg 100 $g^{-1}$of dw, respectively), followed by those harvested from 'Birgah' ungrafted, 'Birgah'/STO, 'Birgah'/SMA, 'Birgah'/SASI, 'Birgah'/SASa2 and 'Birgah'/SIN (7738.2, 5523.5, 7224.9, 3164.0, 4086.0 and 4915.2 mg 100 g^{-1} of dw, respectively) which in turn showed a higher content than 'Birgah'/Msa 2/2 E7 and 'Birgah'/460 CAL., (1988.4 and 1684.0 mg 100 g^{-1} of dw, respectively) (Table 6).

Table 7
Effects of different eggplant rootstocks on total anthocyanins, chlorogenic acid, and glycoalkaloids on fruit of 'Birgah' eggplant scion.

Rootstock	Total anthocyanins (mg 100 g^{-1} of dw)		Chlorogenic Acid (mg 100 g^{-1} of dry weight)		Glycoalkaloids (mg 100 g^{-1} of dry weight)	
2015						
'Birgah' ungrafted	7738.2	abc	1268.2	ns	117.8	ns
STO	5523.5	abc	297.9		34.4	
'Birgah' self-grafted	12413.2	a	1816.4		39.5	
Msa 2/2 E7	1988.4	bc	1647.2		38.2	
460 CAL.	1684.0	c	1185.0		62.1	
SMA	7224.9	abc	986.5		117.4	
SASI	3164.0	abc	1433.0		55.0	
SASa2	4086.0	abc	1032.3		50.6	
SPA	11265.6	ab	976.8		38.5	
SIN	4915.2	abc	1092.3		36.7	

Data within a column and a year followed by the same letter are not significantly different at $p \leq 0.05$ according to Tukey HSD Test.
STO = *S. torvum*; SMA = *S. macrocarpon*; SASI = *S. aethiopicum* (S. indonesia); SASa2 = *S. aethiopicum* (Sa2); SPA = *S. paniculatum* (Jurubeba); SIN = *S. indicum*; Msa 2/2 E7 = double haploid line obtained from anther culture of the tetraploid backcrosses from the somatic hybrid eggplant cv Dourga(+) *S. aethiopicum* with a tetraploid plant of the eggplant line DR2; 460 CAL. = tetraploid hybrid between *S. melongena* and *S. integrifolium*.

ANOVA showed no significant effect of the rootstock in terms of chlorogenic acid and glycoalkaloids content (Table 7).

Rootstock significantly affected protein content (Table 8). 'Birgah'/STO and 'Birgah'/Msa 2/2 E7, showed the highest protein content (15.4, and 15.7 g 100 g^{-1} of dw, respectively), whereas, the lowest values were detected in fruits harvested from 'Birgah'/SMA and 'Birgah'/SASI, (10.4 and 10.5 g 100 g^{-1} of dw, respectively) (Table 8). Rootstock significantly affected Ca content (Table 8); 'Birgah'/SIN gave the highest fruit Ca content. The lowest values were found in fruits harvested from 'Birgah'/SASa2 (95.9 mg 100 g^{-1} of dw). ANOVA displayed that rootstock significantly affected Mg fruit content (Table 8). 'Birgah'/Msa 2/2 E7, 'Birgah'/SASI and 'Birgah'/SIN, revealed the highest Mg content (18.5, 19.7 and 19.4 mg 100 g^{-1} of dw, respectively) (Table 8), whereas, the lowest Mg contents were found in fruits from 'Birgah'/STO, 'Birgah'/SASa2 and 'Birgah'/SPA, (12.8, 16.1 and14.6 mg 100 g^{-1} of dw, respectively) (Table 8). Rootstock significantly affected Na fruit content (Table 8). 'Birgah'/Msa 2/2 E7 showed the highest Na fruit content (81.8 mg 100 g^{-1} of dw), while, the lowest Na fruit content was found in 'Birgah'/SASa2 scion/rootstock combination (58.1 mg 100 g^{-1} of dw). ANOVA for K content showed a significant effect of the rootstock. 'Birgah'/Msa 2/2 E7 and 'Birgah'/460 CAL., displayed the highest K content (366.9 and 353.6 mg 100 g^{-1} of dw, respectively). The lowest K fruit content was found in 'Birgah'/SIN, 'Birgah'/SASI and 'Birgah'/SASa2 (294.3, 291.4 and 294.0 mg 100 g^{-1} of dw, respectively). ANOVA for P fruit content showed a significant effect of the rootstock (Table 8). 'Birgah'/SIN and 'Birgah'/SPA showed the highest P fruit content (573.1 and 555.5 mg 100 g^{-1} of dw, respectively), whereas, 'Birgah'/Msa 2/2 E7 rootstock/scion combination displayed the lowest one (389.8 mg 100 g^{-1} of dw, respectively) (Table 8). ANOVA for Fe fruit content showed a significant effect of rootstock (Table 8). The lowest Fe content was found in 'Birgah' ungrafted (23.1 μg g^{-1}). ANOVA for Cu fruit content revealed a significant effect of the rootstock; 'Birgah'/STO, 'Birgah'/Msa 2/2 E7, 'Birgah'/460 CAL., 'Birgah'/SASI, 'Birgah'/SPA and 'Birgah'/SIN showed the highest Cu fruit content (3.2, 3.2, 2.5, 3.3, 3.1 and 3.2 μg g^{-1}, respectively). The lowest Cu fruit content was found in fruits harvested from 'Birgah' ungrafted (2.2 μg g^{-1}). ANOVA for Mn fruit content displayed a significant effect of the rootstock. 'Birgah'/Msa 2/2 E7 and 'Birgah'/SMA gave higher Mn fruit content (5.88 and 5.96 μg g^{-1}, respectively) than the other scion/rootstock combinations. ANOVA for Zn fruit content revealed a significant effect of the rootstock (Table 8). 'Birgah'/460 CAL., 'Birgah'/SASI and 'Birgah'/SIN showed

Table 8
Effects of different eggplant rootstocks on proteins and mineral fruit content in fruits of 'Birgah' eggplant scion for 2015.

Rootstock	Proteins (g 100 g^{-1} of dw)		Ca (mg 100 g^{-1} of dw)		Mg (mg 100 g^{-1} of dw)		Na (mg 100 g^{-1} of dw)		K (mg 100 g^{-1} of dw)		P (mg 100 g^{-1} of dw)		Fe (μg g^{-1})		Cu (μg g^{-1})		Mn (μg g^{-1})		Zn (μg g^{-1})		Ash (g 100 g^{-1} of dw)	
2015																						
'Birgah' un-grafted	12.8	c	104.0	c	17.0	bc	60.1	ef	327.5	c	491.2	bc	23.1	b	2.2	c	2.88	c	10.0	c	8.60	cde
STO	15.4	a	103.5	c	12.8	e	63.4	bcd	345.3	abc	508.8	b	30.9	a	3.2	a	3.07	c	9.9	c	10.23	b
'Birgah' self-grafted	12.8	c	103.6	c	16.8	bc	60.8	def	335.2	bc	493.0	bc	27.3	ab	2.5	bc	2.89	c	9.7	c	9.17	c
Msa 2/2 E7	15.7	a	106.0	c	18.5	ab	81.8	a	366.9	a	475.8	c	30.8	a	3.2	a	5.88	a	20.0	a	8.49	cde
460 CAL.	12.7	c	105.0	c	17.4	bc	62.1	cde	353.6	ab	489.0	bc	30.6	a	2.5	a	2.77	c	10.0	c	8.34	de
SMA	10.4	e	103.6	c	17.1	bc	62.1	cde	346.5	abc	389.8	d	31.5	a	3.2	bc	5.96	a	18.9	ab	8.50	cde
SASI	10.5	e	103.6	c	19.7	a	64.8	bc	291.4	d	471.3	c	30.9	a	3.3	a	3.58	b	19.9	a	12.57	a
SASa2	11.8	d	95.9	d	16.1	cd	58.1	f	294.0	d	475.0	c	27.4	ab	2.8	ab	3.02	c	18.4	b	5.43	f
SPA	13.5	b	110.6	b	14.6	de	61.1	def	349.0	abc	555.5	a	29.6	a	3.1	a	2.79	c	10.8	c	8.27	e
SIN	12.6	c	117.6	a	19.4	a	65.8	b	294.3	d	573.1	a	30.6	a	3.2	a	3.67	b	19.8	a	9.03	cd

Data within a column and a year followed by the same letter are not significantly different at $p \leq 0.05$ according to Tukey HSD Test.
STO = *S. torvum*; SMA = *S. macrocarpon*; SASI = *S. aethiopicum* (S. indonesia); SASa2 = *S. aethiopicum* (Sa2); SPA = *S. paniculatum* (Jurubeba); SIN = *S. indicum*; Msa 2/2 E7 = double haploid line obtained from anther culture of the tetraploid backcrosses from the somatic hybrid eggplant cv Dourga(+) *S. aethiopicum* with a tetraploid plant of the eggplant line DR2; 460 CAL. = tetraploid hybrid between *S. melongena* and *S. integrifolium*.

the highest Zn fruit content (20.0, 19.9 and 19.8 μg g^{-1}, respectively), whereas, the lowest values were found in 'Birgah' ungrafted, 'Birgah' self-grafted, 'Birgah'/STO, 'Birgah'/460 CAL. and 'Birgah'/SPA (10.0, 9.7, 9.9, 10.0 and 10.8 μg g^{-1}, respectively) (Table 8). ANOVA for Ash fruit content displayed a significant effect of the rootstock (Table 8). The highest values were found in fruits harvested from 'Birgah'/SASI (12.57 g 100 g^{-1} of dw). The lowest Ash fruit content was found in fruits harvested from 'Birgah'/SASa2 (5.43 g 100 g^{-1} of dw) (Table 8).

3.4. Apparent fruit quality

Regarding apparent fruit quality, no significant differences among treatments were found for the fruit curvature (Table 9). In contrast, differences among treatments were found for fruit length. In fact, fruits from 'Birgah' self-grafted, 'Birgah'/Msa 2/2 E7 and 'Birgah'/SPA were significantly more elongated (15.9, 15.7 and 15.4 cm, respectively) than those from 'Birgah' ungrafted, 'Birgah'/STO, 'Birgah'/460 CAL. and 'Birgah'/SASI (14.2, 14.2, 14.1 and 14.6 cm, respectively) which in turn were more elongated than those from plants grafted ontoSMA, SASa2 and SIN (11.9, 12.6 and 11.9 cm, respectively) (Table 9). Fruits harvested from plants grafted onto Msa 2/2 E7 rootstock showed the greatest fruit width (14.0 cm), whereas the lowest fruit widthwas recorded in fruits harvested from 'Birgah'/SIN scion/rootstock combination (11.0 cm). Consequently, the above-mentioned differences in fruit

Table 9
Effects of year and different eggplant rootstocks on apparent fruit quality traits of "Birgah" eggplant scion.

Treatments	Fruit length (cm)		Fruit width (cm)		Fruit length/ width ratio		Fruit curvature (1–9 scale)[1]		Fruit cross-section (1–9 scale)[2]		Fruit calyx length (1–9 scale)[3]		Fruit calyx prickles (0–9 scale)[4]		Seeds index (0–5 scale)[5]	
Year																
2014	14.0		12.6		1.1		1.0		1.5		1.7		3.6		2.8	
2015	14.1		12.7		1.1		1.0		1.5		1.7		3.6		2.8	
Rootstock																
'Birgah' ungrafted	14.2	b	12.8	bc	1.1	bc	1.0	NS	1.5	d	1.2	ef	3.7	bc	2.5	e
STO	15.9	a	13.2	b	1.2	a	1.0		2.0	ab	1.0	f	3.7	bc	2.4	e
'Birgah' self-grafted	14.2	b	12.6	bc	1.1	bc	1.0		1.6	d	1.3	ef	3.7	bc	2.4	e
Msa 2/2 E7	15.7	a	14.0	a	1.1	bc	1.0		1.5	d	1.7	cd	3.0	d	2.0	f
460 CAL.	14.1	b	12.7	bc	1.1	c	1.0		1.8	c	1.5	de	3.5	c	2.8	cd
SMA	11.9	d	12.3	cd	1.0	e	1.0		1.0	e	2.9	a	3.9	ab	3.7	a
SASI	14.6	b	13.0	b	1.1	bc	1.0		1.8	bc	1.9	bc	3.5	c	2.9	bc
SASa2	12.6	c	11.9	d	1.1	d	1.0		1.0	e	1.9	bc	4.0	ab	3.2	b
SPA	15.4	a	13.2	b	1.2	ab	1.0		2.0	ab	1.2	ef	4.1	ab	2.6	de
SIN	11.9	d	11.0	e	1.1	cd	1.0		1.2	e	2.3	bc	3.1	d	3.6	a
Significance																
Rootstock (R)	***		***		***		***		***		***		***		***	
Year (Y)	NS		NS		NS		NS		NS		NS		NS		NS	
R x Y	NS		NS		NS		NS		NS		NS		NS		NS	

Data within a column followed by the same letter are not significantly different at $p \leq 0.05$ according to Tukey HSD Test.
STO = *S. torvum*; SMA = *S. macrocarpon*; SASI = *S. aethiopicum* (S. indonesia); SASa2 = *S. aethiopicum* (Sa2); SPA = *S. paniculatum* (Jurubeba); SIN = *S. indicum*; Msa 2/2 E7 = double haploid line obtained from anther culture of the tetraploid backcrosses from the somatic hybrid eggplant cv Dourga(+) *S. aethiopicum* with a tetraploid plant of the eggplant line DR2; 460 CAL. = tetraploid hybrid between *S. melongena* and *S. integrifolium*.
[1] Measured on a 1–9 scale where 1 = none and 9 = U-shaped according to the European Eggplant Genetic Resources Network (EGGNET) descriptors (Prohens et al., 2005).
[2] Measured on a 1–9 scale where 1 = circular and 9 = very irregular according to EGGNET descriptors.
[3] Relative to the fruit length; measured on a 1–9 scale where 1 = very short (> 10%) and 9 = very long (> 75%) according to EGGNET descriptors.
[4] Measured on a 0–9 scale where 0 = none and 9 = very many (> 30) calyx prickles per fruit according to EGGNET descriptors.
[5] Measured on a 0–9 scale where 0 = none and 5 = very many (> 80) seeds per fruit visible in a longitudinal fruit section.

length and fruit width resulted in differences in fruit length/width ratio (Table 9). Fruits from 'Birgah' grafted onto STO, SPA, 460 CAL. and SASI were significantly more irregular, with a regularity fruit cross-section values of 1.6, 2.0, 1.8 and 1.8, respectively versus those grafted onto SMA, SASa2 and SIN (1.0, 1.0 and 1.2, respectively). Fruits from 'Birgah' grafted onto SMA showed the highest fruit calyx length (2.9) followed by those grafted onto SIN (2.3). The lowest fruit calyx length score was detected in fruits of 'Birgah' self-grafted (1.0) (Table 9). 'Birgah'/SASa2 and 'Birgah'/SPA scion/rootstock combinations displayed the highest fruit calyx prickle scores (4.0 and 4.1, respectively), whereas, the lowest fruit calyx prickle scores were recorded in fruits harvested from 'Birgah'/Msa 2/2 E7 and 'Birgah'/SIN combinations (3.0 and 3.1, respectively). Finally, fruits from 'Birgah' grafted onto SMA and SIN revealed the highest seed index values (3.7 and 3.6, respectively), whereas, the lowest seed index scores were collected in fruits from 'Birgah' grafted onto Msa 2/2 E7 (2.0) (Table 9).

4. Discussion

Grafting of fruiting vegetables is a well-known and effective tool for increasing plant disease resistance or tolerance, yield and fruit quality (Davis et al., 2008a,b; King et al., 2008, 2010; Lee and Oda, 2003; Rivero et al., 2003; Sabatino et al., 2013, 2016). In this article, we studied the effects of several potential rootstocks including both wild/allied species and interspecific hybrids of eggplant on plant vigor, yield and fruit characteristics of 'Birgah' eggplant F_1 hybrid. Our results show that improvements in terms of production, vigor and fruit quality can be accomplished via grafting. On this respect, we have demonstrated that grafting advantages often justify the nursery efforts (rootstock and scion synchronization growth, eggplant rootstock germination, grafting success rates and plantlets establishment) required to produce vigorous and homogeneous eggplant grafted seedlings.

Grafting success is related to several factors such as microenvironment conditions (temperature, humidity and light) during the grafting histological process and graft compatibility (physiological and morphological issues, both related to genetic factors) (Kawaguchi et al., 2008). As described by Bletsos et al. (2003), Lee (1994), Miguel et al. (2007) and Lee et al. (2010), eggplant seedlings are mainly grafted by cleft or tube grafting techniques. In our experiment, adopting the tube grafting method adequately modified by Miceli et al. (2014), grafting success rates ranged from 99.8% to 82.6%. Although *S. torvum* is the phylogenetically most distant rootstock used for eggplant (Isshiki et al., 2008), our study confirms the results obtained by Bletsos et al. (2003) and Rahman et al. (2002), who reported data on successful grafting of eggplant cultivars onto *S. torvum*. Despite the SMA rootstock phylogenetic proximity to eggplant (Furini and Wunder, 2004), our results demonstrated that graft incompatibility might exist. Our results are in accord with those obtained by Gisbert et al. (2011) who, by investigating the eggplant relatives as sources of variation for developing new rootstocks, found that eggplant seedlings grafted with SMA gave a lower percentage of grafting success than those grafted onto STO. Among the rootstocks tested, SIN showed the lowest grafting success rates. Furthermore, this species is less vigorous than other rootstocks used (3.3 kg of aboveground biomass,). The present study suggests that plant vigor may also contribute to decrease grafting success rate. Our results point out also that the two accessions of *S. aethiopicum* gr. *gilo* behaved significantly different for the majority of the recorded traits. This points out the importance of the genetic background employed in consideration of the huge variability available in the wild/allied species of eggplant. Although there are no reports concerning the use of SPA (Jurubeba) as eggplant rootstock, in our study this species gave a good performance in terms of grafting success rates, vigour, fruit quality and yield. As concerning the Msa 2/2 E7 rootstock, our results are in accord with those obtained by Gisbert et al. (2011), who reported a high graft success rate when interspecific hybrids of eggplants were used as rootstocks.

Our experiment showed that rootstock may have a fundamental effect on plant vigor, first flower emission date, yield and fruit quality traits. Plant height, which may be considered an indicator of vigour, was higher in plants grafted onto STO rootstock and lower in plants grafted onto SASa2 rootstock. Regarding the first flower emission date, our results seems to be in accord with those obtained by Gisbert et al. (2011), who found that plant vigour is positively related to fruit earliness. In our study, earlier flowering date was recorded from plants grafted onto STO, Msa 2/2 E7 and SPA rootstocks. Our experiment demonstrates that grafting can be an useful technique to increase the potential productivity of 'Birgah' F_1 eggplant. Plants grafted onto STO, Msa 2/2 E7, 460 CAL. and SMA rootstocks gave a higher marketable yield than ungrafted ones, without any negative effect on average fruit weight because the yield increment was determined by a higher number of marketable fruits. Furthermore, with the only exception of the SASI and SIN rootstocks, our results are in accordance with those obtained by Sabatino et al. (2016) and Maršič et al. (2014) who found that grafted plants produced consistently more fruits per plant than ungrafted ones. Lee (1994) and Colla et al. (2006) associated higher yields in grafted vegetables to increased absorption of water and nutrients.

It is very well-known that grafting can influence fruit quality traits (Alexopoulos et al., 2007; Davis et al., 2008a,b; Gisbert et al., 2011; Proietti et al., 2008; Sabatino et al., 2013), which represent important factors for fruit marketability. Although Muñoz-Falcón et al. (2008) found that fruit shape in eggplant is highly heritable and under genetic control, our study showed that rootstocks may affect cultivar fruit shape parameters such as fruit length, fruit width and fruit length/width ratios. Our results are in accord with those obtained by Gisbert et al. (2011) who, hypothesized that fruit shape changes are probably due to changes in the concentration of growth regulators induced by the rootstock. Muñoz-Falcón et al. (2008) also reported that environment and genotype x environment effects did not affect fruit shape.

Due to the phenolic compounds, eggplant fruit ranks among the top 10 vegetables for the antioxidant activity; consequently, a high fruit pulp browning potential could be expected (Mishra et al., 2013; Singh et al., 2009). Mishra et al. (2013) found that browning appears on cutting, when disruption of cellular structures leads to the release of polyphenol oxidase (PPO) which oxidizes phenolics, and in the presence of oxygen, o-quinones are polymerized, causing brown colored pigments. However, King et al. (2010), Prohens et al. (2007) and Mishra et al. (2013) found, also, that eggplant varieties differed in their extents of post-cut browning, which could be due to variations in the PPO activity or level of soluble phenolics. Our results on pulp browning are consistent with the findings of Moncada et al. (2013), who reported little or no effect of grafting by using STO rootstock. However, we also found that rootstocks tested might positively or negatively affect browning. On this regard, in the present experiment, interesting results were obtained in fruits harvested from plants grafted onto SPA and SMA, which showed the lowest ΔL_{30} values. Chlorogenic acid is the major monomeric phenolic compound in eggplant fruits (Mennella et al., 2010). Our results on chlorogenic acid content are in accord with those of Gisbert et al. (2011) and Moncada et al. (2013), who reported little or no effect of grafting on fruit phenolic content. We did not find a relation between the amount of chlorogenic acid and browning pulp. These results seems to be confirmed by those obtained by Bhowmik and Dris (2004) and by Mennella et al. (2010), who reported a high potential browning variability with respect to other traits, due to the influence of different factors, such as polyphenol quality and quantity, intrinsic enzyme activity and acidity of the medium.

Anthocyanins are the most important group within flavonoids for the production of dark red or purple color of the eggplant peels (Sadilova et al., 2006). Other authors have found that the composition of anthocyanins is largely dependent on eggplant cultivars and growing conditions (Hanson et al., 2006; Raigon et al., 2008; Prohens et al., 2005; Whitaker and Stommel, 2003). Our results on anthocyanins are in accord with those obtained by Maršič et al. (2014), who found that the

concentrations of anthocyanins are highly dependent on grafting. Since, as reported by Manach et al. (2004) and Awad et al. (2001), accumulation of anthocyanins is strongly light-exposure-dependent, it could be additionally suggested that, in order to produce fruits with a higher anthocyanin concentration (higher nutraceutical value), grafted eggplant plants should properly be pruned to guarantee a good light exposure of the fruits (Maršič et al., 2014). 'Birgah' plants grafted onto SPA produced a higher number of leaves than ungrafted 'Birgah' plants, therefore, in our study a leaf shading effect on the fruits might have had a major role in inducing this response.

A variation in glycoalkaloids concentration due to genetic and environmental effects has been reported in potato (Friedman and McDonald, 1997), tomato (Friedman, 2002), and in eggplant (Mennella et al., 2010). Jones and Fenwick, (2006) and Krits et al. (2007) suggested that the level of total glycoalkaloids in potato tubers should not exceed 200 mg/kg of fw (or 200 mg/100 g of dw). Although ANOVA showed no significant effect of the rootstock on glycoalkaloids concentration, our results revealed a certain effect of rootstocks on glycoalkaloids content. The glycoalkaloids concentration ranged from 34.4 to 117.8 mg 100 g^{-1} of dry weight. However, glycoalkaloids amount in fruit from grafted plant was generally below the recommended safety value.

Although self-grafted plants showed little differences from non-grafted plants, changes in overall fruit composition between grafted and ungrafted plants were generally observed. Changes in fruit quality traits of self-grafted plants have been also observed in tomato (Khah et al., 2006) and pepper (Gisbert et al., 2010). Recently, the chromosomal region and QTL (Quantitave Trait Loci) associated to the content of anthocyanin, dry matter, solamargine glycoalkaloid, chlorogenic and other organic acid has been identified in eggplant (Gramazio et al., 2014; Toppino et al., 2016). This may allow, by exploiting the synteny in Solanaceae, to better understand the genetic basis of the effect of grafting on the eggplant fruit composition.

5. Conclusions

Consumers' demand for vegetable fruits rich in compounds important for human health is steadily increasing. Therefore, studies on the effects of different rootstocks on eggplant plant vigor, yield and fruit quality traits can provide improvements both to nurseries involved in grafted seedling production and to eggplant vegetable growers. In particular, the exploitation and valorization of new rootstock genotypes as potential substitutes to those already used, would permit an intensive eggplant crop system in those situations where a rootstock rotation is required. In our study, SPA and the interspecific hybrids Msa 2/2 E7 and 460 CAL. showed a high percentage of grafting success. The eggplant cultivar grafted onto these rootstocks exhibited good vigour and yield. Moreover, these rootstocks did not induce any negative effects on apparent fruit quality traits and fruit composition and, furthermore, the concentration of glycoalkaloids in the fruit remained below the recommended safety value (200 mg/100 g of dw). In conclusion, even though the biotic tolerance to soil borne diseases of SPA and Msa 2/2 E7 and 460 CAL. hybrids must verified, we suggest the above-mentioned rootstocks as potential alternative to *S. torvum*.

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