Article

Influence of Wild Relative Rootstocks on Eggplant Growth, Yield and Fruit Physicochemical Properties under Open Field Conditions

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Abstract: Eggplant is an essential vegetable crop that is rich in health-related compounds, and the content of these compounds can be increased through grafting. It was reported that grafting with vigorous wild relatives' rootstocks can improve eggplant's fruit quality. The study was conducted to investigate the fruit yield, composition and physicochemical traits of *Solanum melongena* ME, CE, NE and TE scions grafted on wild relatives' rootstocks of ST, SM and SI. The results show that a notable graft success (100%) was recorded in grafted (TE/ST) and self-grafted (TE/TE) plants using the cleft technique. Growth and yield traits indicated that CE and TE scions grafted onto ST, SM and SI showed better performance in all of the traits mentioned above in an open field across two years, except first flower formation which was displayed on non-grafted CE. In all the rootstocks studied—ST, SM and SI—there was no noticeable effect on carbohydrate, fibre, ash, pH and dry matter content. There was a notable effect of grafting ME/ST, CE/ST, ME/SM, CE/SI, ME/SI, ME/SI and NE/SM on the fruit length, fruit width, total soluble solids, fruit firmness and fat and protein content, respectively. Furthermore, antioxidants such as DPPH (ME/SM), total flavonoids (NE/SM) and total phenolics (TE/SI) had remarkable content of the above-mentioned physicochemical properties. Results show that ST, SM and SI represent a viable rootstock alternative to *Solanum melongena* or *Solanum lycopersicum* production.

Keywords: wild eggplant relatives; grafting; scion/rootstock combination; vigour; yield; composition; physicochemical

1. Introduction

Eggplant (*Solanum melongena* L.) is commonly cultivated and consumed in Southern and Southeast Asia and has increased in popularity in Malaysia as a specialty vegetable [1]. Globally, the eggplant is ranked as the third most important crop from the Solanaceae family after potato and tomato with an annual production of 55,197,878.00 million tons [2]. The leading producing countries are China and India followed by Egypt, Turkey, Iran, Indonesia, Japan, Italy, Iraq and the Philippines [2]. Rootstocks with good compatibility and tolerance or resistance to biotic and abiotic stresses are ideal for grafting vegetables and also

encourage scion growth, increase production and do not decrease produce quality [3]. Several studies have already been conducted to investigate various eggplant wild rootstocks. *Solanum paniculatum*, for example, increased vigour and fruit yield while having no effect on fruit quality or composition [4]. Tolerance to water and temperature stress was induced by *Solanum incanum* [5], while Fusarium oxysporum tolerance and Ralstonia solanacearum resistance were found in *Solanum aethiopicum* and *Solanum macrocarpon* [6]. *Solanum sisymbriifolium* and *Solanum integrifolium* have been shown to be effective in controlling bacterial wilt and yield increases [7]. Although *Solanum torvum* is the most commonly used rootstock for eggplant and has been reported to be resistant to soil-borne diseases, there is a need to find other alternative rootstocks due to a lack of rapid and homogeneous seed germination [8]. According to Musa et al. [9], grafting wild relatives' rootstocks can have an impact on eggplant yield and apparent fruit quality. Grafting with resistant rootstocks proved to be an effective tool to overcome biotic and environmental stresses and increase yield and quality [8,10]. Presently, *Solanum torvum*, *Solanum macrocarpon* and *Solanum incanum* have been proved as promising rootstocks effective for resistance to soil-borne diseases, tolerance to water and temperature stress, tolerance to abiotic stresses, tolerance to *Fusarium oxysporum* and resistance to *Ralstonia solanacearum* and are frequently used for eggplant grafting [5,8,11]. The whole eggplant fruit has noticeable content of antioxidants and ranks amongst the leading vegetables in terms of antioxidant capacity [12,13].

Grafting vegetables with some certain rootstocks may increase total soluble solids, tataric acids and juice pH [14,15]. Proietti et al. [16] reported that total vitamin C contents for grafted plants were higher than those from non-grafted plants. Research has shown the impact of genotypes on the amount and quality of the phenolic compounds found in eggplant [17,18]. Giorni et al. [19] reported that eggplant grafted onto specific rootstocks had been demonstrated to increase total yield and quality of the fruit (including phytochemical content, for example, phenolic compound). Gisbert et al. [20] reported that Cristal (eggplant) grafted onto *Solanum macrocarpon* rootstocks showed a higher total phenolic content. Sabatino et al. [21] also discovered that eggplant grafted onto *Solanum torvum* enhanced total polyphenol fruit content in four landraces grown in open fields. This research was conducted to (i) assess the influence on eggplant vigour, yield, fruit proximate, physicochemical and antioxidant properties of grafted eggplant traits of wild relatives' ST, SM and SI rootstocks and (ii) identify new potential rootstocks from eggplant wild relatives that may be useful for improving the quality of 'ME, CE, NE and TE' commercial varieties.

2. Materials and Methods

2.1. Plant Material and Growth Condition

Two experiments were conducted in 2019 and 2020 under open field condition at Universiti Putra Malaysia (UPM), Field 10, located between 2°59′ north latitude and 101°42′ east longitude, at altitude of 45 m above sea level. *Solanum melongena* ME, CE, NE and TE scions were grafted onto three potential rootstocks of ST, SM and SI (Table 1). Eggplant *Solanum melongena* ME (Green World Round Purple 311), CE (Yuanza 471), NE (Green World Biocolor Eggplant 321) and TE (Round eggplant 01451/2551) were used as scions. Three potential rootstocks were tested: *Solanum torvum* (ST), *Solanum macrocarpon* (SM) and *Solanum indicum* (SI). Self-grafted and non-grafted controls were included. The experimental design was a randomized complete block and was replicated three times. The planting distance between the rows and between the plants was 70 and 50 cm, respectively. The fertilizers used were NPK green and NPK blue, with recommended doses at two and six weeks after the transplant (DOA, Malaysia). Irrigation and field management was applied to provide a good growing condition. Weather data were collected for monthly maximum and minimum temperature, relative humidity and rainfall for the months from July to October of 2019 and 2020 from the weather station of the experimental field of the ITAFoS, Universiti Putra Malaysia (Table 2).

Table 1. Accessions (*Solanum melongena*) and species used for this study.

No	Code	Original Code	Types of Material	Origin
1	ME	Green World Round Purple 311	Commercial variety	Malaysia
2	CE	Yuanza 471	Commercial variety	China
3	NE	Green World Biocolor Eggplant 321	Commercial variety	Malaysia
4	TE	Round eggplant 01451/2551	Commercial variety	Thailand
5	ST	*Solanum torvum*	Wild relatives	Malaysia
6	SM	*Solanum macrocarpon*	Wild relatives	Nigeria
7	SI	*Solanum incanum*	Wild relatives	Nigeria

Table 2. Monthly maximum and minimum temperatures, relative humidity and rainfall for 2019 and 2020.

Monthly	Temperature		Relative Humidity	Rainfall
2019	Min	Max		
July	25	32	73	168.4
August	25	32	70	158.3
September	25	33	67	125.4
October	25	32	74	383.8
2020				
July	25	32	76	373.3
August	25	33	72	233.0
September	25	32	74	302.4
October	25	32	74	238.5

2.2. Graft Method and Sowing of Plant Material

The rootstock and scion seeds were sown in plastic trays with 108 cells at two different stages in order to have a synchronised stem diameter. The rootstock seedlings were later transplanted into 24 polystyrene propagation trays. Scion seeds were sown one and two weeks later in order to synchronise the stem diameter. Scions at the 2–3 true leaves stage (30–40 days old) were grafted onto rootstock plants having 3–4 true leaves (45–60 days old) using the cleft grafting technique as reported by Lee et al. [22]. Grafted plants were placed in a closed healing chamber, the inside and outside condition of the healing chamber was observed for temperature and relative humidity stability from 8 am to 5 pm, and misting of the grafted chamber was performed twice a day. The chamber was maintained with 80–95% humidity and 26 °C to 30 °C, and the light level was low for 3 to 5 days. The lower temperature and high relative humidity, the shorter the period required for the graft union to heal. After seven days, the plants were removed from the chamber and placed in the greenhouse for hardening. About 14 days after grafting, plants were ready and hardened then transplanted to the field. Graft success was measured as the number of grafts that survived at 14 days after grafting and was recorded as 100 grafted seedlings. Growth parameters were calculated by plant height measured at final harvest, primary branches at 60 DAT. Days to first flower (expressed as DAT) were also recorded. Total yield per plant, number of fruits per plant and fruit weight were calculated. Apparent fruit quality traits (fruit length, fruit width and fruit shape index) of eggplant were assessed. The fruit samples were collected in triplicate for each treatment across the years; at the peak of harvest (2019 and 2020), the fruits were harvested and stored at −80 °C refrigerator for further analysis. All the treatments (grafted, self-grafted and non-grafted) were rinsed under running water to remove dirt from the fruit surface. Subsequently, the fruits were rinsed using double distilled water, followed by blotting with a paper towel to dry the excess water. For proximate analysis, the fruit samples were oven-dried at 50 °C until constant weight.

The dry matter of the eggplant samples was determined using the method outlined by Gisbert et al. [20]. Using this method, the samples were washed and dried in hot-air

Memmert oven (MMT-UF110) maintained at 105 °C for 24 h until constant weight was achieved. The dry matter was expressed using the following equation:

$$DM = \frac{W2}{W1} \times 100$$

where

DM = dry matter
W1 = weight of the fresh sample
W2 = weight of the oven-dried sample

Dry ashing followed the method recommended by AOAC [23]. Crucibles were cleaned using tap water and dried in hot-air Memmert oven (MMT-UF110) for 30 min at 105 °C. The crucibles were then allowed to cool in desiccators, and 2 g of grounded eggplant sample was weighed into the crucible. The crucibles containing the eggplant samples were then transferred into a heated chamber furnace (CARBOLITE ELF) maintained at 550 °C until the samples in the crucible turned light grey ash in colour. The samples were then allowed to cool in a desiccator, and subsequently, the weight was recorded. The ash content was calculated as:

$$\%Ash = \frac{(\text{weight of crucible} + \text{Ash}) - (\text{weight of empty crucible })}{\text{weight of sample}} \times 100$$

Crude protein content was measured from N content determined through Kjedhal method using a Kjeltec 8400 (FOSS) distillation unit according to AOAC [23]. Using this method, 1 g of eggplant sample was measured into a digestion tube (Kjeltec 8400 FOSS) and two tablets of catalyst were added. Approximately 12 mL of concentrated (98%) sulfuric acid (H_2SO_4) was introduced into the samples. The digestion was conducted at 420 °C for an hour in a fume-hood digester. The distillation process was conducted using 50 mL of alkali (40% of NaOH) in a 2200 FOSS distillation unit, and the distillate was collected in 4% boric acid.

The crude fat was determined using fat extractor with an automated control unit (FOSS Soxtec 8000) following the procedure of AOAC [23]. The fat extractor comprised six extraction compartments with individual compartments carrying a thimble that houses the samples and aluminium cups for receiving the extracted fat. The six units of the extractor facilitated the analysis of six samples within a relatively short period of time. In conducting the extraction, 3 g of the eggplant samples was measured into the thimble, the thimble mouth was covered with defatted cotton wool, and this was fitted into the extraction unit. Approximately 150 mL of petroleum ether was measured into each cup, and this was kept at 135 °C. Subsequently, the individual cup was fitted with its appropriate thimble. The extraction and rinsing were conducted for 30 min each, followed by the aeration of sample for 15 min at 105 °C. Crude fat is the percentage of fat expressed as the difference between the weight of the pre-weighed cups and after extraction. The crude fat is calculated as:

$$\%Fat = \frac{W3 - W2}{W1} \times 100$$

where

W1 = weight of the sample
W2 = weight of the empty cup
W3 = weight of cup with the extracted oil

The crude fibre (hot fibre extraction unit) was determined by using Fibertec^TM 2010 (FOSS) following the recommendation of AOAC [23]. Approximately 2 g of the eggplant samples was transferred into clean filter crucibles placed in a crucible stand. The crucible set was loaded with samples, and the stand was hooked in front of the hot extraction unit. Afterwards, 150mL of a solution containing 0.127 M of H_2SO_4 was gently introduced into the hot extraction unit, and heat was applied for 30 min (temperature was gently increased)

at 40 °C to 60 °C. The solution was then washed with boiling water, and the acid was removed. The residue was then boiled in a 150 mL solution containing 0.313 M of NaOH. Subsequently, the mixture was heated between 40 °C and 60 °C (the temperature was gently increased) for 30 min. Finally, there was filtration of the residue through a close pad of washed and ignited asbestos in a Gooch crucible. The residue obtained was then dried in an electric oven, and the weight was afterwards measured. The residue was then incinerated and left to cool, and weight was recorded. The percentage of crude fibre was calculated as:

$$CF\% = \frac{d - c}{a} \times 100$$

where

a = weight of the sample
b = weight of glass crucibles
c = crucible + sample after drying
d = weight of crucible + ash

Carbohydrate contents (dry basis) were estimated using the equation: % Carbohydrates (dry basis) = 100% − Moisture% − Fat% − Protein% − Ash% [24].

The total phenolic content was determined following a slight modification of the Folin–Ciocalteu method by Abu Bakar et al. [25]. Extract solution at 0.15 mL was introduced into 0.75 mL of diluted (1:10 with water) Folin–Ciocalteu reagent. Subsequently, the mixture was allowed to stand for 5 min, after which 0.6 mL of 7.5% (w/v) sodium carbonate was introduced into the mixture, and this was kept for 30 min at room temperature. The total phenolic content of the sample was measured using the Spectrophotometer (1510) Thermo Scientific (USA) at a wavelength of 765 nm (correlation coefficient R^2 = 0.9740). The result was expressed as mg gallic acid equivalents (GAE) per g fresh weight (mg GAE/g FW). The total phenolic content was determined from the equation:

$$TPC = c \, V/m$$

where

TPC = total phenolic content mg GAE/g fresh extract
c = concentration of gallic acid obtained from calibration curve in mg/mL
V = volume of extract in mL
m = mass of extract in gram

The procedure for the determination of total flavonoid content followed a slight modification of the colourimetric method by Abu Bakar et al. [25]. A mixture was prepared from 1 mL extracts and sodium nitrite solution (4 mL, 1:5, w/v), and this was left to stand for 6 min, after which aluminium chloride solution (0.3 mL, 1:10, w/v) was introduced into the mixture. After this, 1 M sodium hydroxide solution (2.0 mL) was introduced into each extract, and this was followed by incubation of the mixture for 10 min at room temperature. The total flavonoid content of the sample was measured using the Spectrophotometer (1510) Thermo Scientific (USA) at a wavelength of 510 nm (correlation coefficient R^2 = 0.9963). Results were expressed as mg catechin equivalents (CE) per g fresh weight (mg CE/g FW). The total flavonoid content was determined from the equation:

$$TFC = c \, V/m$$

where

TFC = total flavonoid content mg GAE/g fresh extract
c = concentration of gallic acid obtained from calibration curve in mg/mL
V = volume of extract in mL
m = mass of extract in grams

The procedure for the determination of DPPH followed a modification of the colourimetric method Aadesariya et al. [26] 2017. The procedure followed the preparation of 1 mM

solution of DPPH in ethanol and 1 mg/1 mL extract solution in ethanol. Thereafter, 1.5 mL of this solution was added to 1.5 mL of DPPH. The absorbance was read at a wavelength of 517 nm against a blank solution made from 3ml ethanol and control O.D. made from 3 mL DPPH. The assay was prepared in three replicates. Spectrophotometer (1510) Thermo Scientific (USA) was used. The ratio inhibition of free-radical DPPH was determined from control reading using the following equation:

$$\text{DPPH scavenged (\%)} \frac{\text{A control } - \text{A test}}{\text{A control}} \times 100$$

The procedure for determining total ascorbic acid was conducted using the method reported by Hanson et al. [27]. This entails the combination of 2, 4-dinitrophenylhydrazine (DNPH) with the ketonic groups of dehydroascorbic acid through the oxidation of ascorbic acid by 2, 6-dichlorophenolindophenol (DCPIP) to obtain a yellow-orange colour under acidic conditions [28]. An amount of 20 g of the frozen slurry was mixed with 80 mL, 5% meta-phosphoric acid in a homogenizer. Thereafter, the mixture was blended and centrifuged. Subsequently, 2 mL of the supernatant was introduced into a 20 mL test tube containing 0.1 mL of 0.2% 2, 6-DCPIP sodium salt in water, 2 mL of 2% thiourea in 5% metaphosphoric acid and 1 mL of 4% 2, 4-DNPH in 9 N sulfuric acid. This mixture was placed in a water bath at 37 °C for 3 h and later into an ice bath for 10 min. Approximately 5 mL of 85% sulfuric acid was introduced into the mixtures, and the mixtures were left for 30 min at room temperature prior to reading at OD 520 nm. The Spectrophotometer (1510) Thermo Scientific (USA) was used. Thereafter, 2, 4-DNPH was introduced into the ice bath as a blank for control. The calibration was prepared from commercial L- (+) -ascorbic acid.

Total soluble solids (Brix) from each part were measured from the juice obtained from each part, refractometer (MTD-045nD, Three-In-One Enterprises Co. Ltd., Taiwan) was used, and an average was taken and replicated three times. The pH of the fruit was read using a CRISON (meter) electrode pH meter GLP21 after blending the fruit with a blender and sieving the juice; an average was calculated and was expressed as pH of fruit juice. Flesh fruit firmness was measured using digital penetrometer (Fruit Firmness Universal Testing Machine, 825 University ave, Norwood, MA, USA (Instron) 5543 model), the fruit was punched in two opposite points of the equatorial part, and firmness was determined by measuring the fruit's resistance to the plumber.

2.3. Statistical Analysis

The data on growth, yield, apparent fruit quality, proximate, nutritive and health-related compounds across the two years were analysed via two-way analysis of variance (ANOVA) (year (Y) × rootstock (R)), using analysis software (SAS) program version 9.4 (SAS Institute, Inc., Cary, NC, USA), while means were separated using least significant difference (LSD) at $p = 0.05$. For chemical analysis, the linear regression equation for a straight line was used. $Y = mx + c$ where Y = absorbance of extract, m = slope of the calibration curve, x = concentration of extract, and c = intercept.

3. Results

3.1. Grafting Success

The cleft grafting method was successful with an over 90% degree of success in all combinations including self-grafted (Figure 1). High graft success was observed in TE scion grafted onto ST rootstock (100%) and self-grafted TE/TE (100%), which were not statistically different from the graft combination 'NE/ST, ME/ST, TE/SM and TE/SI', whereas CE scion grafted onto SM rootstock had relatively lower graft success, which was not statistically different from ME/ST, CE/ST, NE/SM and CE/SI.

Figure 1. Graft success (%) with cleft grafting techniques, with significance level *p* = 0.05.

3.2. Plant Growth and Yield across Years

Across years, growth ad yield traits were affected by grafting ($p \leq 0.01$), while years affected total yield traits ($p \leq 0.01$) and fruit number per plant and plant height ($p \leq 0.05$). No significant differences were observed in first flower formation, number of primary branches and fruit weight (Table 3). On the other hand, interaction between years and the rootstock affected ($p \leq 0.01$) fruit weight and total yield per plant traits. No significant differences were observed in first flower formation, plant height and number of primary branches (Table 3). The mean showed that rootstocks did not significantly affect first flower formation (Table 2). Non-grafted CE had earlier flowering at 49.83 days after sowing (DAS), although self-grafted ME produced late flowers at 78.00 DAS. Plant height at final harvest was significantly affected by the rootstocks (Table 3). CE grafted onto ST had the highest plant height (83.40 cm), whereas self-grafted CE/CE had the shortest plant (52.96 cm). Rootstocks significantly influenced the number of primary branches per plant at final harvest (Table 3). The highest branches were recorded in CE scion grafted onto SI rootstock (3.91) which was not statistically different with non-grafted TE (3.76), whereas the lowest value was recorded in TE grafted onto SM. The result shows that rootstocks significantly increased the fruit weight (Table 3). CE grafted onto SM (515.88 g) had the weightiest fruit compared to their counterpart non-grafted CE (308.17 g) and self-grafted CE/CE (348.23 g), while NE/ST had the lowest fruit weight (131.63 g).

For the number of fruits per plant (Table 3), self-grafted ME/ME (55.00) and grafted TE/ST (54.17) had the highest fruit number, which was not statistically different from ME, CE/ST, NE/SM and ME/SI, while self-grafted TE/TE had the lowest number of fruit (22.17). Rootstocks significantly increased yield (Table 3); CE grafted onto ST had the highest total fruit yield (4.48 kg) compared to the non-grafted CE (2.56 kg) and self-grafted CE/CE (3.01 kg) counterparts. Meanwhile, non-grafted TE (1.37 kg) had the lowest value.

Table 3. Rootstock effects on growth and yield traits of 'ME, CE1, CE, NE and TE' commercial scions.

Cultivar	First Flower	Plant Height (cm)	Primary Branches	Fruit Weight (g)	Number of Fruit/Plant	Total Yield/Plant (kg)
Year						
2019	62.81 a	67.40 a	2.71 a	235.65 b	46.22 a	3.96 a
2020	62.92 a	62.00 b	2.87 a	321.82 a	35.86 b	2.83 b
Rootstock						
ME	68.67 fg	71.43 c	2.17 gh	242.89 i	44.83 a–e	3.51 e
CE	49.83 l	62.24 ef	2.09 h	308.17 g	35.67 c–i	2.56 i
NE	66.33 h	66.34 d	2.48 ef	142.23 lm	25.33 ghi	2.53 i
TE	65.50 h	56.52 i	3.76 ab	134.29 mn	30.83 f–i	1.37 l
ME/ME	78.00 a	70.62 c	2.20 gh	360.76 e	55.00 a	3.78 c
CE/CE	50.67 kl	52.96 j	2.16 gh	348.23 f	31.00 c–i	3.01 gh
NE/NE	69.33 ef	61.92 ef	2.64 de	134.76 mn	30.67 f–i	2.88 h
TE/TE	70.67 cd	55.15 i	3.69 b	145.53 l	22.17 i	2.04 k
ME/ST	70.83 c	58.55 gh	2.64 de	383.52 d	38.17 b–g	3.24 f
CE/ST	72.00 b	83.40 a	2.62 de	492.73 b	51.67 ab	4.48 a
NE/ST	70.83 c	78.90 b	2.34 fg	131.63 n	46.00 a–d	4.06 b
TE/ST	51.00 k	62.89 e	2.98 c	146.20 l	54.17 a	3.46 e
ME/SM	50.67 kl	62.04 ef	2.67 de	403.66 c	48.67 abc	3.14 fg
CE/SM	53.67 ij	63.22 e	2.23 gh	515.88 a	37.17 c–h	2.00 k
NE/SM	53.50 j	62.80 ef	2.15 gh	167.00 jk	35.50 c–i	3.69 cd
TE/SM	54.67 i	56.83 hi	2.07 h	175.27 j	39.33 b–f	4.08 b
ME/SI	70.33 cde	61.04 f	2.76 d	284.26	47.33 abc	3.18 f
CE/SI	69.67 def	62.17 ef	3.91 a	314.91 g	23.67 hi	2.21 j
NE/SI	68.17 g	58.68 g	3.57 b	164.57 k	32.17 d–i	2.88 h
TE/SI	69.00 fg	65.93 d	3.58 b	165.21 jk	38.67 b–g	3.61 de
Significance						
Rootstock (R)	**	**	**	NS	*	**
Year (Y)	NS	**	NS	*	**	**
R × Y	NS	NS	NS	*	NS	**

Data within a column followed by the same letter are not significantly different at $p \leq 0.05$ according to LSD 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; NS = not significant.

3.3. Apparent Fruit Quality and Physicochemical Traits across Years

The results show that years affected ($p \leq 0.01$) traits such as dry matter, fibre and protein content, whereas significant differences ($p \leq 0.05$) were observed in pH, fat, carbohydrate content and ascorbic acid. No significant differences were observed in fruit length, fruit width, fruit length/width ratio, total soluble solids, fruit firmness, ash content DPPH, total flavonoid content and total phenolic content. Interaction between rootstock and year affected ($p \leq 0.01$) protein and ($p \leq 0.05$) carbohydrate content, while others showed no significant difference. The mean showed that rootstocks significantly affected fruit length (Table 4). ME grafted onto ST (32.07 cm) had the highest fruit length compared to their non-grafted ME (23.72 cm) and self-grafted ME/ME (29.65 cm) counterparts. However, within the same cultivar, self-grafted plants had higher fruit length compared to non-grafted (Table 4). Rootstocks significantly affected fruit width (Table 4). CE grafted onto ST had a comparably higher fruit width (14.29 cm) than their self-grafted (7.84 cm) and non-grafted (7.71 cm) counterparts. However, within the same cultivar, self-grafted plants outperformed their non-grafted counterparts. In this study, fruit length/width ratio was also affected by rootstocks (Table 4). ME grafted onto SM had the highest fruit length/width ratio (3.46 cm) compared to their self-grafted (3.27 cm) and non-grafted (2.85 cm) counterparts. The total soluble solids (Brix) were significantly higher in the grafted plant with the SI rootstock and CE scion (7.36) compared to non-grafted (5.20) and self-grafted (6.18) controls, while cultivars ME and TE produced the lowest Brix (4.30 and 4.33, respectively) (Table 4). For fruit firmness, ME grafted onto SI (45.02) had the highest fruit firmness, compared to their control counterparts (non-grafted and self-grafted) ME (28.86) and ME/ME (24.11), respectively. Fruit pH was not influenced by the rootstocks

(Table 4). Non-grafted plant NE had the highest pH (5.74) which was not statistically different from self-grafted NE/NE (5.72) and grafted NE/ST (5.70), while NE grafted onto SI had the lowest pH (5.30).

Table 4. Rootstock effects on growth and yield traits of 'ME, CE, NE and TE' commercial scions.

Genotypes	Fruit Length (cm)	Fruit Width (mm)	Fruit Shape Index (Ratio)	Total Soluble Solids (°Brix)	Fruit Firmness (Ncm^2)	pH
2019	24.21 a	10.75 a	2.31 a	5.94 a	32.89 a	5.68 a
2020	21.96 a	10.50 a	2.14 a	6.15 a	31.40 a	5.33 b
Rootstock						
ME	23.72 d	8.33 l	2.85 c	4.30 p	28.86 l	5.43 i
CE	18.52 f	10.89 f	1.73 jk	5.20 m	34.01 f	5.52 efg
NE	14.12 i	7.88 m	1.79 ij	5.08 n	32.69 h	5.74 a
TE	12.34 j	7.71 m	1.60 l	4.33 p	34.92 d	5.42 i
ME/ME	29.65 b	9.08 hij	3.27 b	5.40 k	24.11 p	5.56 e
CE/CE	18.68 f	12.06 d	1.58 l	6.18 e	34.09 f	5.46 hi
NE/NE	16.17 h	8.46 l	1.91 ghi	5.58 i	29.22 k	5.72 ab
TE/TE	14.51 i	7.84 m	1.85 hij	6.13 f	33.38 g	5.36 j
ME/ST	32.07 a	9.65 g	3.32 b	6.45 c	27.42 n	5.65 cd
CE/ST	29.04 b	14.29 a	2.04 fg	5.26 l	28.39 m	5.68 bc
NE/ST	21.46 e	9.30 h	2.31 d	5.53 j	27.40 n	5.70 ab
TE/ST	19.27 f	8.94 ij	2.17 e	5.19 m	28.37 m	5.35 j
ME/SM	31.60 a	9.14 hi	3.46 a	5.90 g	27.58 n	5.61 d
CE/SM	27.04 c	13.07 c	2.07 ef	4.95 o	26.52 o	5.48 gh
NE/SM	19.08 f	11.56 e	1.66 kl	7.08 b	34.55 e	5.51 fg
TE/SM	19.30 f	10.87 f	1.78 jk	6.34 d	40.67 b	5.43 i
ME/SI	23.04 d	9.70 g	2.37 d	5.69 h	45.02 a	5.54 ef
CE/SI	20.78 e	13.61 b	1.54 l	7.36 a	37.61 c	5.34 jk
NE/SI	17.14 g	8.81 jk	1.95 fgh	7.08 b	32.08 i	5.30 k
TE/SI	17.19 g	8.54 kl	2.013 fg	5.71 h	30.12 j	5.47 hi
Significance						
Rootstock (R)	**	NS	*	**	**	**
Year (Y)	NS	NS	NS	NS	NS	**
R × 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 LSD 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; NS = not significant.

In terms of dry matter content (Table 5), self-grafted CE/CE and TE/TE recorded the highest dry matter (7.39 and 7.33), which was not statistically different from NE/SM, TE/SM and CE/SI (7.15, 6.91 and 7.21, respectively), while low dry matter was observed in non-grafted CE and grafted CE/SM. As usual, eggplants grafted with vigorous rootstocks had a significant effect on fat content (Table 5). Fat content in ME scion grafted onto SI rootstock (6.69) was higher compared to non- and self-grafted plants 'ME' (3.14 and 3.40, respectively). Significant difference was also observed in crude fibre contents (Table 5). The content with the highest value was observed in non-grafted plants CE/CE and TE/TE (3.50 and 3.41, respectively), whereas the lowest content was recorded in grafted CE/ST and NE/ST (2.38 and 2.37, respectively). Rootstocks did not significantly affect ash content (Table 5). High ash content values were observed in TE non-grafted (10.58) and TE/TE self-grafted (10.50) plants, while the lowest ash content was recorded in NE/NE (7.30) which was not statistically different from non-grafted NE (7.37). In terms of carbohydrate content (Table 5), the highest value was observed in non-grafted ME (70.42), whereas the lowest was recorded in self-grafted TE/TE (63.66) and grafted NE/SM (63.52).

Table 5. Rootstock effects on growth and yield traits of 'ME, CE, NE and TE' commercial scions.

Genotypes	Dry Matter (%)	Fat Content	Fibre Content	Ash Content	Carbohydrate Content (%)
Year					
2019	7.03 a	3.83 a	3.12 a	9.13 a	66.95 a
2020	6.26 b	3.23 b	2.42 b	9.01 a	67.62 a
Rootstock					
ME	6.12 ghi	3.14 fg	3.08 cd	8.89 gh	70.42 a
CE	5.73 i	1.91 h	2.96 def	10.33 b	68.48 de
NE	6.64 c–f	4.58 c	2.99 def	7.37 kl	69.20 c
TE	6.07 hi	4.47 c	3.18 bc	10.58 a	64.70 j
ME/ME	6.44 d–h	3.40 ef	2.81 gh	8.82 h	69.86 b
CE/CE	7.39 a	2.15 h	3.50 a	10.14 c	66.65 h
NE/NE	6.37 e–h	5.27 b	3.25 b	7.30 l	68.60 de
TE/TE	7.33 a	4.22 c	3.41 a	10.50 a	63.66 k
ME/ST	6.79 b–e	3.07 fg	2.87 fgh	9.50 d	68.28 ef
CE/ST	6.16 f–i	2.05 h	2.38 i	8.93 fg	69.01 cd
NE/ST	6.31 e–h	1.75 h	2.37 i	8.97 fg	69.53 bc
TE/ST	6.65 c–f	2.73 g	2.79 gh	9.08 e	67.80 fg
ME/SM	6.64 def	4.29 c	2.95 def	9.02 ef	68.40 e
CE/SM	5.78 i	1.94 h	2.04 j	10.20 c	68.30 ef
NE/SM	7.15 abc	4.14 cd	3.08 cd	10.20 c	63.52 k
TE/SM	6.91 a–d	3.70 de	3.04 d	10.17 c	65.97 i
ME/SI	6.61 d–g	6.69 a	2.78 h	7.41 k	65.56 i
CE/SI	7.21 ab	4.37 c	3.03 de	8.45 ij	66.62 h
NE/SI	6.80 b–e	4.37 c	2.91 efg	8.40 j	66.80 h
TE/SI	6.77 b–e	3.26 ef	3.06 cd	8.53 i	67.67 g
Significance					
Rootstock (R)	*	**	**	**	**
Year (Y)	**	*	**	NS	*
R × Y	NS	NS	NS	NS	*

Data within a column followed by the same letter are not significantly different at $p \leq 0.05$ according to LSD 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; NS = not significant.

Rootstocks significantly influenced protein content (Table 6) which showed that the highest value was observed in NE scion grafted onto SM rootstock (14.99) compared to its counterparts non-grafted (12.21) and self-grafted (12.47). For ascorbic acid (Table 6), self-grafted ME/ME (35.80) had the highest values for this parameter, which was not statistically different from grafted plants CE/ST (34.98), ME/SI (38.08) and CE/SI (35.13), while the least value (24.57) for ascorbic acid was recorded in non-grafted TE. In terms of DPPH (Table 6), the highest DPPH was reported in ME scion grafted onto SI rootstock (79.01), compared with the non-grafted (66.79) and self-grafted (69.13) counterparts, whereas the lowest value (48.09) was obtained in self-grafted TE/TE and grafted NE/SM (47.51) plants.

Significant difference was also observed in total flavonoid contents (Table 6). The highest value for total flavonoid content was recorded in NE scion grafted onto SM rootstock (721.99), compared with the non-grafted (501.89) and self-grafted (486.74) counterparts, while the lowest value (255.62) was observed in non-grafted ME and self-grafted ME/ME (486.74). Grafting of eggplant onto wild relative rootstocks showed a significant effect on total phenolic content (Table 6). TE/SM rootstock had the highest content of total phenolics (380.56), compared with the non-grafted (219.72) and self-grafted (252.55) counterparts, whereas the lowest value (106.41 and 109.11) was recorded in grafted CE/ST and CE/SI.

Table 6. Rootstock effects on growth and yield traits of 'ME, CE, NE and TE' commercial scions.

Genotypes	Protein Content (%)	Ascorbic Acid (mg/g FW)	DPPH (%)	Total Flavonoid Content (mg CEQ/g FW)	Total Phenolic Content (mg GAE/g FW)
Year					
2019	13.39 b	31.33 a	63.27 a	530.87 a	240.66 a
2020	14.21 a	29.74 b	61.23 a	466.28 a	216.78 a
Rootstock					
ME	13.43 k	28.36 f	66.79 f	255.62 p	167.54 ij
CE	13.56 j	33.65 b	67.17 f	319.83 o	129.96 k
NE	12.21 n	29.49 ef	72.29 bc	501.89 f	208.29 fg
TE	14.17 d	24.57 g	58.50 h	354.65 m	219.72 f
ME/ME	13.47 k	35.80 a	69.13 e	262.52 p	133.03 k
CE/CE	13.67 hi	28.87 ef	72.80 b	470.26 h	178.96 hi
NE/NE	12.47 m	31.05 cd	70.00 de	486.74 g	178.78 hi
TE/TE	14.29 c	28.13 f	48.09 l	363.62 kl	252.55 e
ME/ST	14.38 b	28.37 f	72.93 b	358.47 lm	184.00 h
CE/ST	13.85 e	34.98 ab	70.85 cd	366.62 k	106.41 l
NE/ST	13.44 k	28.42 ef	54.43 j	582.79 d	316.92 bc
TE/ST	13.75 fg	28.05 f	56.67 i	656.23 b	270.17 d
ME/SM	13.66 hi	31.77 c	50.32 k	362.91 kl	200.67 g
CE/SM	13.78 f	29.22 ef	62.22 g	406.57 i	134.65 k
NE/SM	14.99 a	28.78 ef	47.51 l	721.99 a	329.34 b
TE/SM	13.70 gh	28.07 f	58.88 h	658.16 b	380.56 a
ME/SI	13.75 fg	35.08 ab	79.01 a	333.05 n	156.13 j
CE/SI	13.36 l	35.13 ab	66.93 f	376.37 j	109.11 l
NE/SI	13.63 i	28.62 ef	72.16 bc	563.59 e	306.01 c
TE/SI	13.34 l	29.93 de	55.08 j	596.14 c	250.70 e
Significance					
Rootstock (R)	**	**	**	NS	NS
Year (Y)	**	*	NS	NS	NS
R × Y	**	NS	NS	NS	NS

Data within a column followed by the same letter are not significantly different at $p \leq 0.05$ according to LSD 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; NS = not significant.

4. Discussion

In this research, evidence showed that grafting with high-vigour rootstocks may increase the yield and quality of the fruit. The increased yield and fruit quality proven in this study is consistent with earlier reports on grafting [9,14,21]. The success of grafting is determined by graft combination, rootstock and scion compatibility, temperature, humidity and light [20,29]. In this research, the results show that the cleft grafting technique was highly successful, with more than 90% graft success in all treatments. The result is supported by Musa et al. [9], who reported significant graft success in MCV1, MCV2 and TCV scions grafted with wild eggplants using the cleft technique. As shown by our result, grafting with compatible rootstocks produced earlier flowers than self-rooted, for example, TE/SM, TE/ST and NE/SM. The results are consistent with the previous study of graft incompatibility and environmental stress [9,20]. At final harvest, plant height, which is usually regarded as a measure of vigour, was also affected by grafting. Improved vigour due to rootstock grafting in CE/ST, CE/SM and TE/SI was also evident in the values observed for plant height and number of branches, as a result of improved water uptake and greater capacity for assimilation, absorption and nutrient uptake [9].

According to this study and earlier research, the increase in total yield of grafted plants compared with non-grafted and self-grafted plants was frequently due to the higher weight of the fruit or number of fruits. The scions CE and NE grafted onto ST rootstocks and TE scions grafted onto SM rootstocks outperformed non-grafted and self-grafted plants in terms of total yield, without any negative effects on the number of fruits per plant, since the increase in yield was determined by the number of fruits and fruit weight. Our

findings are congruent with that of Sabatino et al. [21], who observed that grafted plants had consistently more fruits per plant than non-grafted and self-grafted plants.

Higher yields in grafted plants were linked to increased water and nutrient absorption, according to Lee [30] and Colla et al. [31]. The result agreed with Khah et al. [32], who observed that fruit weight was higher in grafted plants than in their non-grafted counterparts. Fruit quality is essential for marketability, and grafting can influence fruit quality attributes [9,14,15,20,33]. Our research found that rootstocks had an impact on fruit shape parameters such as fruit length, width and fruit shape index (ME/ST, CE/ST and ME/SM, respectively). The findings are consistent with those of Gisbert et al. [20], who showed that fruit shape changes are most likely due to the changes in the concentration of growth regulators generated by the rootstocks. In this study, Brix significantly increased in some eggplants grafted with ST, SM and SI rootstocks. ME/ST, NE/SM, TE/SM and CE/SI had higher Brix than plants from the non-grafted and self-grafted counterpart 'ME, NE, TE and CE' treatment, which is in accord with existing literature where a similar effect was reported by Martinez-Ballesta et al. [34], Mohammed et al. [35] and Flores et al. [36]. Our result also shows that some graft combinations with vigorous rootstocks did not consistently result in increased fruit quality. These findings demonstrate that it is possible to record an increase, decrease or no changes in quality parameters of fruits from grafted plants. For example, grafted CE/SM was lower than non-grafted and self-grafted 'CE' treatments. This agrees with the result reported by existing literature [14,20,36]. The result on fruit firmness shows a significant increase in eggplants grafted with the SM and SI rootstocks, which is in accord with existing literature reported by Lee [30], Nkansah et al. [37] and El-Wani et al. [38]. The pH tends to prolong the shelf life of fresh fruits by inhibiting the multiplication of microorganisms and increasing resistance to microbial attack [39]. The result on pH shows a significant increase in eggplants grafted with certain ST, SM and SI rootstocks and ME and CE onto ST. Improvement of fruit pH on grafting with certain rootstocks has been documented [14,32,40]. Previous research has also produced inconclusive results regarding changes in fruit flavour and nutritional attributes as a result of grafting with specific rootstocks. Grafting with specific rootstocks improved some quality attributes while having neutral or negative effects on others [36,40,41]. Our findings indicate that rootstocks had no effect on fruit dry matter when compared to grafting with self-grafted and non-grafted plants which produced the highest dry matter content (CE and TE), though self-grafted CE/CE was not statistically different from grafted plants CE/SI. The dry matter performance was inconsistent, depending on the rootstock and scion used, and was better in non-grafted and self-grafted plants [20], whereas lower dry matter was recorded in grafted plants.

The findings are in accord with those obtained by Davis et al. [14] and Turhan et al. [42], who reported decreased dry matter in grafted fruits. However, Sabatino et al. [33] reported a contrary observation stating that fruit dry matter produced by grafted plants was higher, compared to self- and non-grafted plants. Grafting with wild rootstocks may affect fruit fat content. Our result shows that plants grafted with wild rootstocks produced the highest fat content (ME/SI) which may be due to the selection of vigorous rootstocks, improved scions and the growing environment. Generally, changes in the proximate compositions were observed, suggesting that grafting with vigorous rootstocks may enhance the uptake of water and nutrients and growth hormone regulator balance [41]. Fibre is one of the most important indigestible parts of food crops, such as vegetables. Results from our study indicate that the crude fibre decreased in grafted fruits, compared to control (CE/CE, NE/NE, TE/TE and TE). Based on our result, it can be concluded that crude fibre may be influenced by the selection of scions and rootstocks. Our result shows that rootstocks may not affect fruit ash content, which may be due to high mineral content in the non-grafted and self-grafted plants (TE and TE/TE). Our result is contrary to Sabatino et al. [33] (2013), who noted that fruits harvested from grafted plants had higher ash content compared to non-grafted plants. Changes in the proximate compositions were observed, indicating that grafting may induce modifications associated with growth regulator balance.

Grafting with wild relative rootstock SM could affect fruit proximate traits such as crude protein. Results from this study are similar to those reported by Sabatino et al. [33] and Gisbert et al. [43], who claimed that grafted plants had higher amounts of protein in comparison with their non-grafted counterparts. Rouphael et al. [40] also reported that fruit quality traits of grafted plants may be influenced by the scions and rootstocks selected. Changes in proximate compositions were generally observed, indicating that grafting vigorous rootstocks may induce modifications that are associated with growth regulator balance. This claim was supported by Khan et al. [32], Gisbert et al. [43] and Tabitha [44] who reported that grafting with vigorous rootstocks may affect the quality of the final product [45]. The result obtained in this study shows that the carbohydrate content decreased in grafted fruits, compared to non-grafted fruits (ME). However, the result is contrary to Gherghi et al. [46], who reported that carbohydrate content was slightly higher in fruits produced from grafted plants in comparison to those from non-grafted plants. Similarly, Gheorghita et al. [47] in an experiment on hybrids noted that 'Kaiser F1' rootstock directly influenced the content of carbohydrates.

The result on ascorbic acid showed a significantly higher level of ascorbic acid in eggplants grafted with wild rootstocks, and this was attributed to the effect of the wild rootstocks ST and SI used. This result is corroborated by Sanchez-Rodriguez et al. [48] and Chavez-Mendoza et al. [49], who reported that grafted fruits had higher ascorbic acid content compared with non- and self-grafted fruits. However, contrary results by Qaryouti et al. [50] and Di Gioia et al. [51] suggest that ascorbic acid traits were lower in grafted plants compared to un-grafted and self-grafted. The result on antioxidant activity (DPPH) shows a significant increase in the DPHH of eggplants grafted with ST and SI rootstocks. This finding is in contrast with past studies reported by Vinkovic Vrcek et al. [52], who stated that the antioxidant activities of SIo grafts 'Efialto' and 'Maxifort' grafted onto 'Tamaris' were significantly lower compared to their respective rootstocks and scions. Martínez-Valverde et al. [53] and Raffo et al. [54] reported that antioxidant properties depend largely on lycopene content, phenolic compounds and ascorbic acid. Total flavonoid content is an antioxidant and health-related compound. Results on total flavonoid content show significantly higher flavonoid content in eggplants grafted with wild SM and ST rootstocks. This is in accord with a previous report by Nicoletto et al. [55] who reported that under water stress, the use of a drought-tolerant rootstock (cv. Zarina) increased the concentration of total flavonoids, hydroxycinnamic acids and rutin compared to non-grafted or self-grafted 'Zarina'.

Furthermore, some graft combinations with vigorous rootstocks showed an inconsistent increase in nutrient concentrations. Riga et al. [56], in their study, noted that a decrease or increase in flavonoids was influenced by the choice of rootstocks when a similar scion cultivar was grafted. As shown by the drought study, rootstocks that are well adapted to stress conditions responsible for higher flavonoid production may lead to an improvement in total flavonoids in the entire plant [48]. The phenolic compounds present in eggplant fruit made it one of the leading vegetables in terms of antioxidants [57,58]. Higher phenolic concentration may be a further indication of stress in the rootstock/scion combination, as stress conditions enhance the build-up of phenolics [59,60]. The result on total phenolic content showed more phenolics in eggplants grafted with ST and SM rootstocks. This result is similar to those obtained by Gisbert et al. [20], Sabatino et al. [21] and Kumar et al. [61], who reported in their studies on fruit composition traits that higher fruit phenolic content was found in grafted plants compared to their un-grafted counterparts.

5. Conclusions

The demand for vegetable fruits that are high in chemicals that are beneficial to human health is rapidly increasing. As a result, research into the impact of diverse rootstocks on eggplant plant vigour, yield and quality features may benefit eggplant vegetable growers. This research showed that using a variety of rootstocks can improve eggplant plant vigour and production, apparent fruit quality, flavour-related attributes, fruit proximate and

nutritionally important content and health-promoting antioxidants. In our study, eggplants from ST rootstocks showed an effect in plant height, number of fruits per plant, fruit width and total yield per plant. SM rootstock showed a higher effect on fruit weight, fruit length, fruit index, protein content and total phenolic content. SI rootstock showed a higher effect on the number of branches, total soluble solids, fruit firmness, fat content and DPPH. We suggest that crosses could be made with the above-mentioned rootstocks and *Solanum melongena* to develop interspecific hybrids that could serve as potential substitutes for existing wild rootstocks. This will provide good germination and the best intensive eggplant cropping system.

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