

IMPACT OF GRAFTING ON WATERMELON GROWTH, FRUIT YIELD AND QUALITY

Fouad H. MOHAMED, Khalid E. Abd EL-HAMED, Mohammed W.M. ELWAN,
Mennat-Allah N.E. HUSSEIN

Department of Horticulture, Faculty of Agriculture
Suez Canal University, Ismailia, Egypt 41522.

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Summary

Grafting is an alternative approach to reduce crop damage resulting from soil-borne pathogens and increases plant abiotic stress tolerance, which in turn increases crop production. The purpose of this study was to determine whether grafting could improve plant growth and fruit quality of watermelon through monitoring the changes induced by different rootstock-scion combinations. Watermelon (*Citrullus lanatus*) cv. Aswan F₁ was grafted into five rootstocks (Nun 6001 F₁, Strongtosa F₁, Tetsukabuto F₁, Ferro F₁ and Shintoza F₁) hybrids between *Cucurbita maxima* and *Cucurbita moschata*. Highest vegetative growth and fruit yield were obtained by 'Nun 6001 F₁' as a rootstock using the tongue approach method. Grafting reduced significantly sex ratio by reducing the number of male flowers. Grafting increased significantly lycopene content in fruit flesh by 57% over the control treatment, but did not affect soluble solids content (SSC). One third of the control non-grafted plants died and *Fusarium oxysporum* was isolated as the responsible pathogen. These results indicate that grafting watermelon onto specific rootstock influences growth, productivity, and quality of the fruit as well as disease resistance. Grafting can be suggested as an alternative method to control of *Fusarium* wilt in watermelon production.

key words: grafting, *Citrullus lanatus*, rootstock, yield, lycopene content, *Fusarium* wilt

INTRODUCTION

Even though grafting has been practiced in fruit trees for thousands of years (Ashita 1927), vegetable grafting has been only recently widely adopted on a commercial scale (Sakata *et al.* 2007). The early use of grafted vegetables was associated with pro-

tected cultivation which involves successive cropping. Fortunately, seed companies have been able to select and/or breed well-adapted scion cultivars for intensive growing. Although the benefits of using grafted seedlings are widely recognized, many other factors must be carefully considered to ensure successful cultivation and

satisfactory income with this new technology, especially in developing countries such as Egypt. For example, extensive use of chemical fertilizers and synthetic pesticides should be minimized for the production of environmentally friendly produces, in which interest has been exploding in recent years (Davis *et al.* 2008b). It has been well-known that the use of proper rootstocks can minimize the problems associated with successive cropping and stress tolerance (Huang *et al.* 2010).

The advantages of vegetable grafting have been noticed by many workers. Grafts were used to induce resistance against low and high temperatures (Rivero *et al.* 2003, Venema *et al.* 2008), enhance nutrient uptake (Pulgar *et al.* 2000, Colla *et al.* 2010a), increase synthesis of endogenous hormones (Dong *et al.* 2008), improve water use efficiency (Rouphael *et al.* 2008), reduce uptake of persistent organic pollutants from agricultural soils (Otani & Seike 2007), improve alkalinity tolerance (Colla *et al.* 2010b), raise salt tolerance (Martinez-Rodriguez *et al.* 2008, He *et al.* 2009), and limit the negative effect of heavy metal toxicity (Savvas *et al.* 2010).

The scion variety affects size, yield, and quality of fruit in grafted plants, but rootstock effects can drastically alter these quality characteristics (Davis *et al.* 2008a). The quality characteristics might be affected by grafting as a result of the translocation of metabolites associated with fruit quality to the scion through the xylem and/or modification of physiological processes of the scion (Rouphael *et al.* 2010). There are several conflicting reports concerning the change in fruit

quality due to grafting and whether grafting is an advantageous or deleterious (Proietti *et al.* 2008, Flores *et al.* 2010). The total sugar content of watermelon grafted onto bottle gourd (*Lagenaria siceraria* (Mol.) Standl.) rootstock was reported to be lower than self-rooted watermelon (Qian *et al.* 2004, Liu *et al.* 2006). However, Miguel *et al.* (2004) and Huitr  n-Ram  ez *et al.* (2009) found no difference in soluble solid concentrations in watermelon fruit from scions grafted onto a squash interspecific hybrid (Shintoza) compared to control. Also, Proietti *et al.* (2008) found that the total soluble solid (TSS) concentration was similar in grafted and un-grafted plants, while Salam *et al.* (2002) showed a marked increase in grafted watermelon soluble solids.

Red-fleshed watermelon is rich in lycopene, a member of the family of carotenoids that are among the most important antioxidants in nature (Di Mascio *et al.* 1989). Substantial amount of research reported on the health benefits of diets rich in lycopene for the prevention of certain types of cancer (Hadley *et al.* 2003) as well as cardiovascular disease (Sesso *et al.* 2003). Proietti *et al.* (2008) demonstrated that mini-watermelon grafted onto the commercial hybrid rootstock ‘PS 1313’ (*Cucurbita maxima* Duchesne $\times$ *Cucurbita moschata* Duchesne) showed increase in lycopene concentration by 40% in comparison to those recorded on un-grafted plants. Similarly, Davis and Perkins-Veazie (2005) reported that grafting watermelon increased lycopene and total carotenoids by 20%. On the other hand, Bruton *et al.* (2009) showed that grafting had no

effect on watermelon fruit lycopene content.

Grafting can also exhibit excellent tolerance to serious soil-borne diseases, such as those caused by *Fusarium*, *Verticillium*, *Phytophthora*, *Pseudomonas*, *Didymella bryoniae*, *Monosporascus cannonballus*, and *nematodes* (Louws et al. 2010) even though the degree of tolerance varies considerably with the rootstocks. The increased vigor from the rootstock allows the plant to develop despite the pathogen (Cohen et al. 2000). Grimault et al. (1994) suggested that resistant rootstocks physically limit the movement of bacteria from the soil to the scion. Also, substances translocated from the rootstock to the scion through xylem were suggested as a factor in disease resistance (Lee 1994). The metabolic and protein changes that appear in the xylem fluid may be a key to understand host resistance to *Fusarium* wilt (Biles et al. 1989). Wu et al. (2010) reported that root exudates from resistant watermelon rootstocks suppressed *Fusarium oxysporum* growth while exudates from susceptible rootstocks favored the growth.

Watermelon is one of the most popular and widely used vegetable crops in the world. Approximately 3.41 Million ha are planted yearly with watermelon all over the world and yielding 98 Million tons with an average of 28.72 tons/ha (FAOSTAT 2009). Egypt produced 1.5 Million tons from around 0.05 Million ha with an average of 30 tons/ha. Egypt occupied the eighth rank in watermelon cultivated area in the world (FAOSTAT 2009). Egyptian soils especially in Ismailia region, a tradi-

tional watermelon production area, are heavily infected with *Fusarium* wilt (Ali et al. 1972, El-Shami 1984, Abd-El-Naby 2001, El-Marzoky & El-Sharkawy 2011). However, with the restriction of using methyl bromide for soil fumigation, growers became aware of using grafted transplants to manage soil-borne diseases. There are only few reports on vegetable grafting under the Egyptian conditions due to the limited use of this technique in commercial production as a result of the high cost of rootstocks and facilities.

Several studies on grafting effects on watermelon plant growth and fruiting characteristics under normal as well as stress conditions have been conducted. However to our knowledge, limited research has been done on the effects of grafting on increasing resistance to soil-borne disease under the Egyptian conditions as well as improving important health-related compounds, such as lycopene. Therefore, the objective of this investigation was to determine the effects of grafting cv. Aswan F₁ onto five different rootstocks on plant growth, flowering characteristics, percentage of survival, resistance to *Fusarium* wilt, fruit yield and quality, under Ismailia region conditions.

MATERIALS AND METHODS

Three field experiments were conducted at the Experimental Research Farm of Faculty of Agriculture, Suez Canal University, Ismailia, Egypt, during the two successive spring-summer season of 2010 and 2011 (from January 15 to June 17, 2010 and 2011 for the first two exper-

iments and from February 2 to June 20, 2011 for the third experiment) to test the effect of five different genotypes used as rootstocks on plant growth performance, sex ratio, fruit yield and quality of watermelon cv. Aswan F₁ used as scion.

Plant material

Watermelon (*Citrullus lanatus* [Thunb.] Natsum & Nakai) cv. Aswan F₁ (Sakata Company, Japan) was used as non-grafted control. This cultivar is widely grown in commercial production of watermelon in Egypt, especially in Ismailia region. The hybrids 'Nun 6001 F₁', 'Strongtosa F₁', 'Tetsukabuto F₁', 'Ferro F₁' and 'Shintoza F₁' (*Cucurbita maxima* x *Cucurbita moschata*), released by Nunhems Zaden (The Netherlands), Syngenta Seeds (The Netherlands), Takii Seeds (Japan), Rijk-Zwaan and G.S.I Seeds (The Netherlands), respectively were used as rootstocks. 'Nun 6001 F₁' and 'Shintoza F₁' are among the most popular rootstocks commercially available for watermelon grafting worldwide (Miguel *et al.* 2004, King *et al.* 2010).

The seeds of the rootstocks were sown 10-14 days earlier than the seeds of the scions to ensure similar stem diameters at the grafting time due to the differences in growth vigor. Seeds were sown in 130-cell styrofoam trays under greenhouse conditions. The trays were filled with soil mixture (peatmoss, vermiculite and perlite mixes in 1:1:1 v/v/v). The environmental conditions for germination were 24-28°C and 85-90% relative humidity. Tongue approach grafting method was the best grafting method for watermelon as reported by Hussien (2011) and was used in this study as described by Hassell *et al.* (2008).

First two watermelon experiments

These experiments were conducted during spring-summer season of 2010 and 2011 to test the effectiveness of the three rootstocks ('Nun 6001 F₁', 'Strongtosa F₁' and 'Tetsukabuto F₁') on improving plant growth and fruit yield of watermelon cv. Aswan F₁. Grafting combinations were as follows: Aswan F₁/Nun 6001 F₁, Aswan F₁/Strongtosa F₁, Aswan F₁/Tetsukabuto F₁ and 'Aswan F₁' (non-grafted, control).

Twelve plants per graft combination and treatment were transferred to the greenhouse after the grafts have been established (2 weeks after grafting). Grafted plants were then hand planted in rows 2.0 m in width, 12 m in length and spaced 1.0 m apart in the open field. A randomized complete block design was adopted with 3 replications, each consisting of 4 plants. The grafted and control plants were cultivated from 18 March 2010 and 2011 to 17 June 2010 and 2011. Irrigation, fertilization and pesticide application followed the standard cultural practices of watermelon in Egypt.

The following measurements were recorded during both growing seasons: (a) main stem length (cm/plant), number of lateral stems and number of leaves, all of them after 7 weeks from the cultivation in the field; (b) number of dead plants; (c) flower characters such as number of male and female flowers (measured weekly). Also, sex ratio was calculated by divided number of male flowers by number of female flowers; (d) selective harvests were performed 2-3 times from the end of May until the end of the experiment. The harvested fruits per plant and per hectare were

weighed and the average fruit weight (g per fruit) was recorded.

In addition, the following parameters were recorded only in the second experiment: (a) fresh and dry weight of foliage growth: Three plants per graft combination were picked up and weighted then dried in the oven at 70°C for three days to determine dry weights, (b) fruit skin thickness (cm); (c) fruit circumference (cm); and (d) SSC of the juice obtained from the central endocarp was determined using hand Refractometer according to A.O.A.C. (1996).

Third watermelon experiment

This experiment was carried out during spring-summer season of 2011 to compare between the best rootstock from the first experiment (Nun 6001 F₁) and two other rootstocks (Ferro F₁ and Shintoza F₁) using tongue approach grafting method, on their effects on plant growth, fruit yield and quality of watermelon cv. Aswan F₁. Grafting combinations were as follows: Aswan F₁/Nun 6001 F₁, Aswan F₁/Ferro F₁, Aswan F₁/Shintoza F₁ and 'Aswan F₁' (non-grafted, control). In addition to the measurements recorded in the first two experiments, the lycopene content was determined according to Ranganna (1977) and was calculated using the following equation:

$$\text{Mg of lycopene per 100 g FW} = \frac{3.1206 \times \text{optical density (OD) of sample} \times \text{volume made up} \times \text{dilution} \times 100}{1 \times \text{wt of samples} \times 1000}$$

Isolation and identification of the *Fusarium oxysporum*

Samples of the infected roots and basal stems of the collected diseased watermelon plants were thoroughly washed with running water for several

times, cut into small pieces, disinfested by immersion them into sodium hypochlorite solution (0.5%) for two minutes, passed in sterilized distilled water and dried between two sterilized filter papers. Small pieces of the sterilized root or basal stem samples were separately placed into Petri dishes (9 cm) containing potato dextrose agar (PDA) medium and incubated at 28°C for 3-7 days. Petri dishes were examined daily. The developing fungal colonies were purified by hyphal tip technique. Pure cultures of all isolated fungi were maintained on PDA slants till identification. The isolated fungi and fungal-like organisms were examined microscopically and identified according to the description of Booth (1971) and Barnett and Hunter (1986).

Data analysis

Data were statistically analyzed using ANOVA/MANOVA of Statistica 6 software (Statsoft 2001, Tulsa, OK, USA) with mean values compared using Duncan's Multiple Range Test with a significance level of at least * P < 0.05, ** P < 0.01 and *** P < 0.001.

RESULTS

1- First two watermelon experiments

1-1. Shoot growth characteristics

Results obtained from the first and second experiments are summarized in Tables 1&2 and Fig. 1. Generally, length of main stem, number of lateral stems and number of leaves of watermelon cv. Aswan F₁ were significantly higher by grafting onto Nun 6001 F₁ in the first experiment. However, plants grafted onto 'Tetsukabuto F₁' had the highest values in the second

experiment in comparison to grafted plants onto other rootstocks and non-grafted plants (Table 1). In most cases, the lowest values were associated with non-grafted plants in both seasons. Concerning the fresh and dry weight of vegetative growth, the results in Table 2 showed that the grafted plants onto 'Tetsukabuto F₁' rootstock had significantly highest values comparing with plants grafted onto other rootstocks. Also, the results indicated that all grafted plants stayed alive until the end of the experiment, however approximately one third of the non-grafted plants died at the end of the experiment (Table 1). Regarding shoot dry weight percentage, the results in Table 2 showed no clear difference between grafted and non grafted plants.

1-2. Flowering and fruiting characteristics

Regarding to flowering characters, the grafted and non-grafted plants did not show any significant differences (Table 1), especially in the second experiment. Also, data in the first experiment indicated that grafted plants onto 'Strongtosa F₁' gave the highest female flower number and the lowest sex ratio, however, the lowest female flower number and the highest sex ratio were found in non-grafted plants (Table 1). Fruit yield characteristics were significantly affected by rootstock (Fig. 1). Fruit yield per plant increased by 30.6%, 7.04% and 18.45% during 2010, however, the increase in percentages in second

experiment were 38.3%, 16.7% and 61.4% when 'Aswan F₁' plants grafted onto 'Nun 6001 F₁', 'Strongtosa F₁' and 'Tetsukabuto F₁' respectively. Also, fruit yield per hectare increased by 95.8%, 60.51% and 47.98% in 2010, however, it increased by 106.4%, 74.12% and 140.92% when 'Aswan F₁' plants grafted onto 'Nun 6001 F₁', 'Strongtosa F₁' and 'Tetsukabuto F₁', respectively. Our results indicated that the fruit yield and average fruit weight did not significantly differ when watermelon cv. 'Aswan F₁' was grafted onto 'Tetsukabuto F₁' or 'Nun 6001 F₁' in the second experiment, conversely, grafted plants onto 'Nun 6001 F₁' produced the highest fruit yield and average fruit weight during 2010. As regards to fruit yield per plant and average fruit weight, grafted plants onto 'Strongtosa F₁' did not show any significant differences comparing with non-grafted plants in season of 2011 (second experiment). The presented results showed that the fruit yield per hectare increased by 4.4%, when watermelon cv. 'Aswan F₁' was grafted onto 'Nun 6001 F₁' in season of 2010 in comparison to 2011, but, percentage of increase was 61.3% when 'Tetsukabuto F₁' was used as scion. Concerning fruit skin thickness and fruit circumference, the results in Table 2 showed slight differences in all grafted and non grafted plants. Soluble solids content was not significantly affected by grafting.

Table 1. Plant vigor and flowering traits of 'Aswan F₁' grafted onto 'Nun 6001 F₁', 'Strongtosa F₁' and 'TetsukabutoF₁' rootstocks and control

Scion/Rootstock	Leaf No.	Length of main stem	Lateral stems No.	Survival %	Male flower	Female flower	Sex ratio
2010							
Aswan F ₁ /6001 F ₁	127.25 a	265.67 a	24.17 a	100.0 a	55.8 a	27.4 ab	2.06 ab
Aswan F ₁ /Strongtosa F ₁	78.33 bc	238.25 a	14.33 c	100.0 a	49.0 a	31.6 a	1.62 b
Aswan F ₁ /Tetsukabuto F ₁	93.33 b	177.50 b	20.00 b	83.3 ab	55.6 a	29.0 ab	1.99 ab
Control (non-grafted)	68.25 c	135.17 c	17.00 bc	66.7 b	50.0 a	20.8 b	2.37 a
2011							
Aswan F ₁ /6001 F ₁	127.6 b	222.4 b	15.40 b	100.0 a	25.6 a	10.80 a	2.40 a
Aswan F ₁ /Strongtosa F ₁	129.4 b	215.3 b	16.50 b	100.0 a	26.5 a	11.30 a	2.30 a
Aswan F ₁ /Tetsukabuto F ₁	141.0 a	241.8 a	23.00 a	100.0 a	36.0 a	15.25 a	2.40 a
Control (non-grafted)	105.8 c	195.0 c	14.75 b	66.7 b	29.0 a	13.60 a	2.17 a

Values are the means of 6 plants per grafting treatment. Values followed by the same letter within a column are not significantly different at the 0.05% level of probability according to Duncan's multiple range test

Table 2. Shoot fresh and dry weight, percentage of shoot dry weight, soluble solids content, fruit skin thickness and fruit circumference of 'Aswan F₁' grafted onto 'Nun 6001 F₁', 'Strongtosa F₁' and 'TetsukabutoF₁' rootstocks and control during spring-summer 2011

Scion/Rootstock	Shoot FW (g/plant)	Shoot DW (g/plant)	Shoot DW %	SSC	Fruit skin thickness (cm)	Fruit circumference (cm)
Aswan F ₁ /6001 F ₁	1226.7 b	313.33 b	25.55 b	5.52 a	1.73 ab	57.50 ab
Aswan F ₁ /Strongtosa F ₁	1176.7 b	311.15 b	26.44 ab	4.95 a	1.77 ab	51.17 b
Aswan F ₁ /Tetsukabuto F ₁	1853.3 a	501.55 a	27.06 a	6.03 a	1.54 b	59.50 a
Control (non-grafted)	888.0 c	234.59 c	26.42 ab	5.73 a	1.78 a	59.00 ab

Values are the means of 3 plants or fruits per grafting treatment. Values followed by the same letter within a column are not significantly different at the 0.05% level of probability according to Duncan's multiple range test

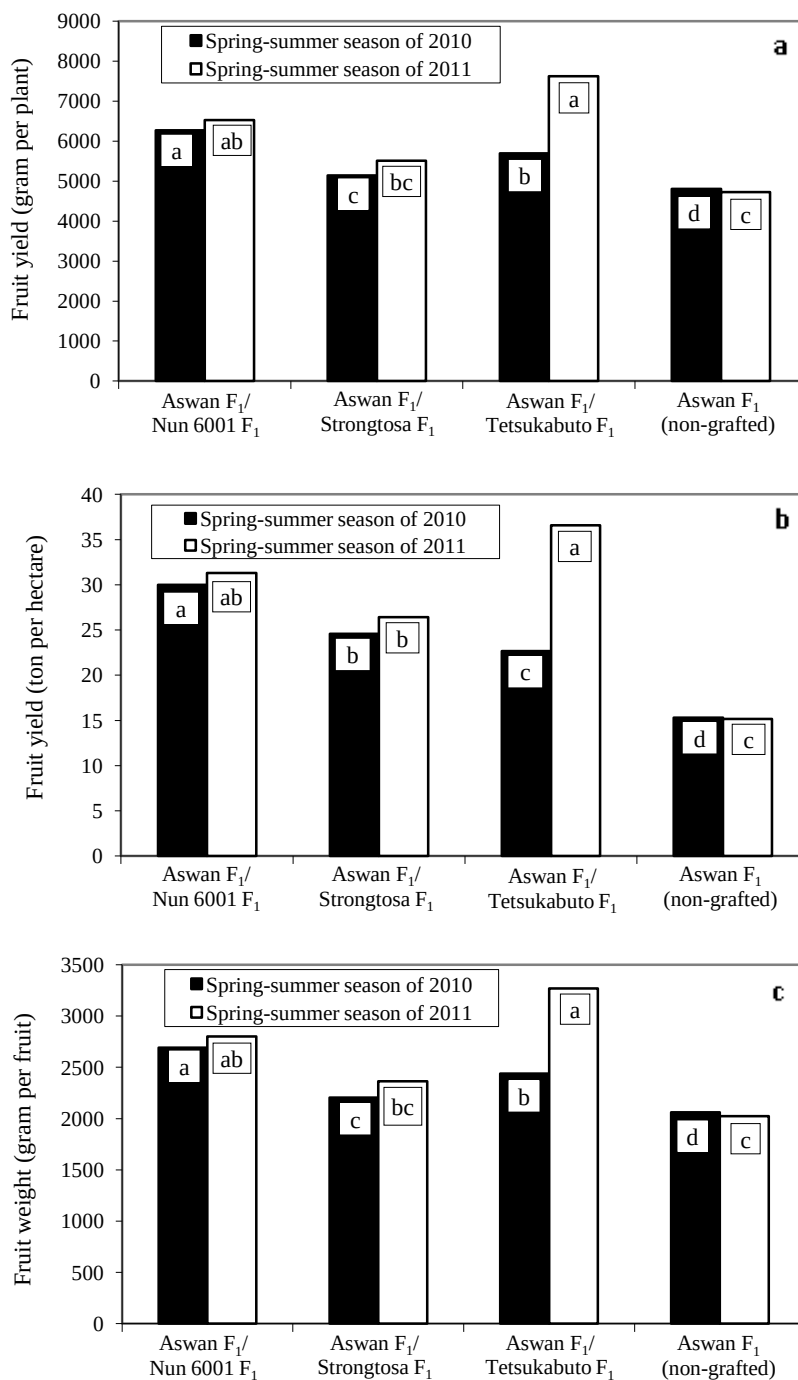


Fig. 1. Fruit yield per plant (a), fruit yield per hectare (b) and average fruit weight (c) 'Aswan F₁' grafted onto 'Nun 6001 F₁', 'Strongtosa F₁' and 'Tetsukabuto F₁' rootstocks and control. Values followed by the same letter are not significantly different at the 0.05% level of probability according to Duncan's multiple range test

2. Third watermelon experiment

2-1. Shoot growth characteristics

Data presented in Table 3 revealed that grafted plants onto ‘Nun 6001 F₁’ and ‘Shintoza F₁’ had the highest number of leaves comparing with grafted plants onto ‘Ferro F₁’ and non-grafted plants. Also, the results showed that grafted plants using all tested rootstocks significantly gave the highest length of main stem and

number of lateral stems. Data presented in Table 3 illustrated that grafted plants onto ‘Shintoza F₁’ and ‘Nun 6001 F₁’ rootstocks produced significant higher shoot fresh weight and dry weight percentage, however, the significant higher shoot dry weight was associated with the grafted plants onto ‘Shintoza F₁’ followed by grafted plants onto ‘Nun 6001 F₁’ as rootstock.

Table 3. Plant vigor of watermelon Aswan F₁’ grafted onto ‘Nun 6001 F₁’, ‘Ferro F₁’ and ‘Shintoza F₁’ rootstocks and control

Scion/ Rootstock	Leaf No.	Length of main stem	Lateral stems No.	Shoot FW (g/plant)	Shoot DW (g/plant)	Shoot DW%	Survival %
Aswan F ₁ / 6001 F ₁	170.33 a	438.00 a	17.17 a	3650.0 a	905.00 b	24.79 a	100.0 a
Aswan F ₁ / Ferro F ₁	137.00 b	437.00 a	16.33 a	2850.0 b	610.25 c	21.42 b	91.67 a
Aswan F ₁ / Shintoza F ₁	168.50 a	473.40 a	16.17 a	4150.0 a	1066.50 a	25.72 a	100.0 a
Control (non-grafted)	116.50 b	363.33 b	12.00 b	3050.0 b	638.25 c	20.92 b	68.33 b

Values are the means of 6 plants per grafting treatment. Values followed by the same letter within a column are not significantly different at the 0.05% level of probability according to Duncan’s multiple range test

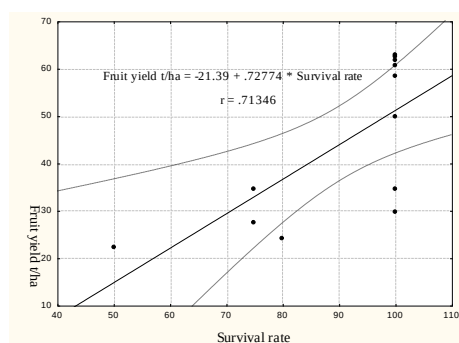


Fig. 2. Regression of fruit yield on survival ratio (%) of plants of ‘Aswan F₁’ watermelon cultivar grafted onto three rootstocks. The dashed lines represent the 95% confidence interval on the whole regression line

Concerning plant survival, results (Table 3) pointed out that plant survival was 100% with ‘Nun 6001 F₁’ and ‘Shintoza F₁’ rootstocks, however, survival was over 91% with ‘Ferro F₁’ rootstock. The survival percentage of the non-grafted plants was low (68.33%). The survival of the plants was the main factor in the determination of fruit yield, since both parameters were closely related, as shown in Fig. 2 ($r = 0.71$, $**P < 0.01$). The most common isolated microorganism associated with root rot and wilt of watermelon non-grafted plants was identified as *Fusarium oxysporum* (Fig. 3).

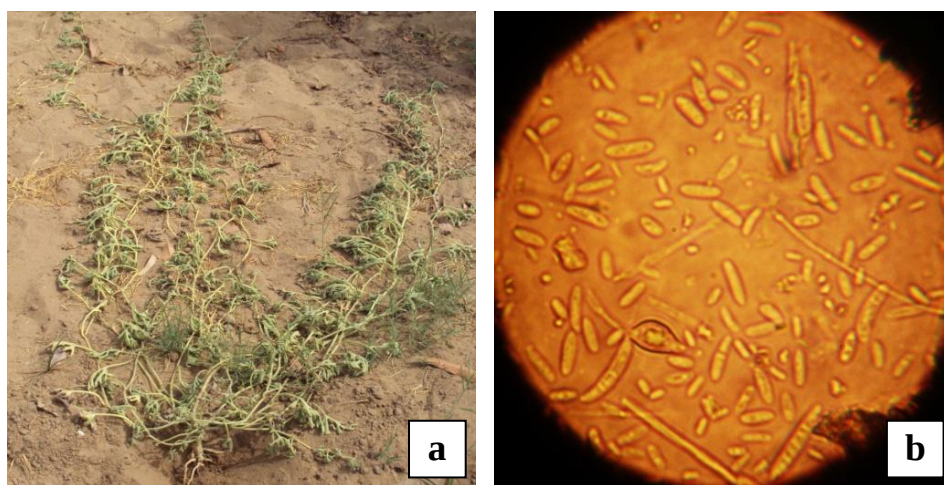


Fig. 3. Morphology of wilted non-grafted plant (a) and microphotograph showing spores of *Fusarium oxysporum* isolated from wilt non-grafted plant (b)

2-2. Flowering and fruiting characteristics

Regarding flower characters, the results obtained (Table 4) indicated that the grafted plants onto 'Nun 6001 F₁' had the significant lowest number of male flowers in comparison to other grafting treatments as well as non-grafted plants. Also, the results showed

that non-grafted plants had significantly highest sex ratio comparing with all grafted plants using all rootstocks. However, grafted plants onto 'Shintoza F₁' and 'Nun 6001 F₁' gave highest number of female flowers per plant, followed by grafting plants onto 'Ferro F₁', and un-grafted plants.

Table 4. Flowering traits, fruit circumference, fruit skin thickness, soluble solids content and lycopene content of 'Aswan F₁' grafted onto 'Nun 6001 F₁', 'Ferro F₁' and 'Shintoza F₁' rootstocks and control

Scion/ Rootstock	Male flower	Female flower	Sex ratio	Fruit circum- ference (cm)	Fruit skin thickness (cm)	SSC	Lycopene content (mg/100 g FW)
Aswan F ₁ / 6001 F ₁	25.75 b	20.50 ab	1.28 b	51.17 a	2.03 a	10.38 a	6.24 a
Aswan F ₁ / Ferro F ₁	29.40 a	19.60 b	1.50 b	55.16 a	2.05 a	10.13 a	6.73 a
Aswan F ₁ / Shintoza F ₁	31.00 a	24.17 a	1.29 b	51.00 a	1.72 b	10.20 a	5.64 a
Control (non-grafted)	32.00 a	14.40 c	2.34 a	49.50 a	1.80 ab	10.78 a	3.95 b

Values are the means of 3 plants or fruits per grafting treatment. Values followed by the same letter within a column are not significantly different at the 0.05% level of probability according to Duncan's multiple range test

Concerning fruit yield, results in Fig. 4 revealed that grafting onto 'Shintoza F₁' and 'Nun 6001 F₁' significantly increased fruit yield per plant, fruit yield per hectare, and fruit weight comparing with grafting onto "Ferro F₁" and non-grafted plants. The increase in fruit yield per plant was 42.9% and 40.6%, while the increase in fruit yield per hectare was 105.1% and 101.8% and in fruit weight was 34.8% and 42.1% in grafted plants onto 'Shintoza F₁' and 'Nun 6001 F₁', respectively. Besides, the results proved no significant differences between grafted plants onto "Ferro F₁" and non-grafted plants in all fruit yield characters.

Regarding to fruit skin thickness, the results revealed that the lowest value was found in fruits obtained from plants grafted onto 'Shintoza F₁' rootstock, however, the highest values were observed in watermelon fruits harvested from plants grafted onto 'Nun 6001 F₁' and 'Ferro F₁' rootstocks. Concerning fruit circumference and SSC, results showed that no significant differences were detected

using the grafting technique with the three different rootstocks. On the other hand, the lycopene content was generally higher in fruit from grafted plants comparing to un-grafted ones (Table 4). The differences were statistically significant and represented 57% increase. Fruits harvested from plants grafted onto the rootstocks Ferro F₁, Nun 6001 F₁ and Shintoza F₁ gave higher lycopene content by 70.4%, 58% and 42.8% over those from un-grafted plants, respectively (Table 4).

The performance of 'Aswan F₁' watermelon plants grafted onto 'Nun 6001 F₁' and grown in un-fumigated *Fusarium* infested soils in the 3-year period of experiments is illustrated in Fig. 5. In these trials, un-grafted plants of 'Aswan F₁' were served as control. It is clear that in all performed experiments during the three consecutive years, both plant survival and yield were higher in the grafted plants than in the controls. In general the non-grafted plants failed to produce yield comparable to grafted plants.

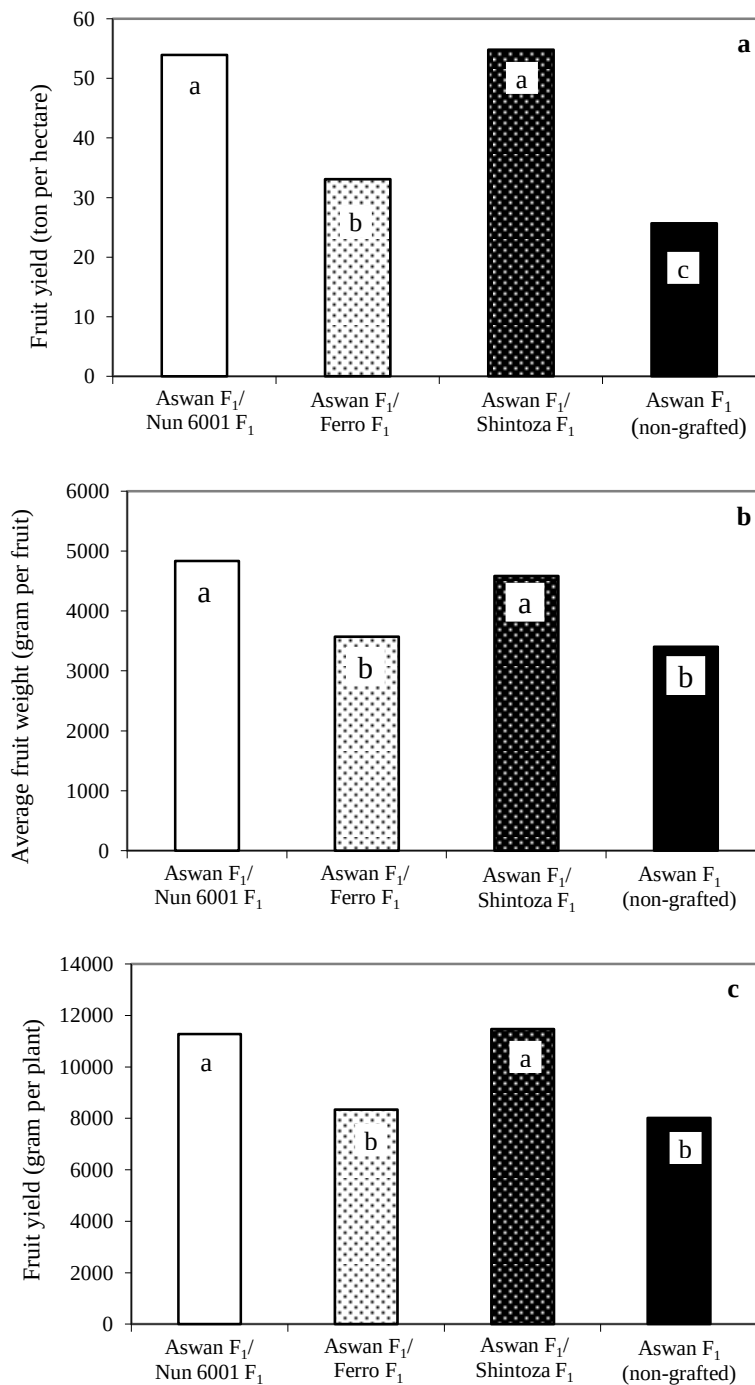


Fig. 4. Fruit yield per plant (a), fruit yield per hectare (b) and average fruit weight (c) 'Aswan F_1 ' grafted onto 'Nun 6001 F_1 ', 'Ferro F_1 ' and 'Shintoza F_1 ' rootstocks and control. Values followed by the same letter are not significantly different at the 0.05% level of probability according to Duncan's multiple range test

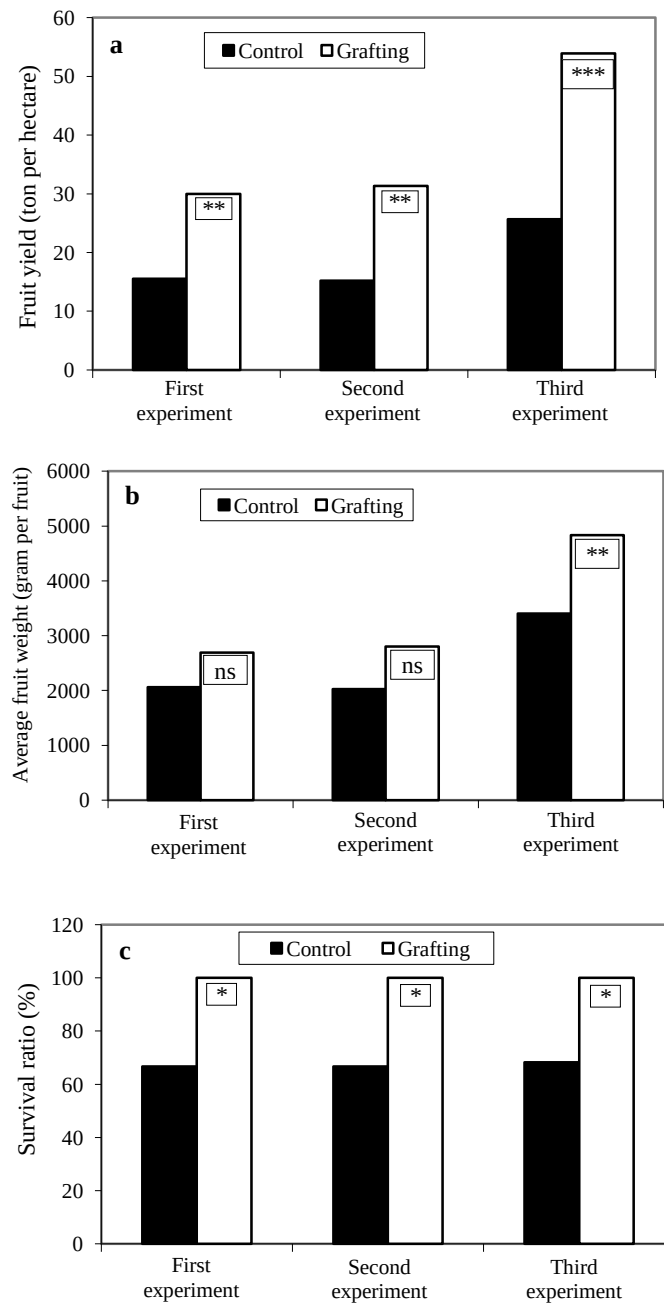


Fig. 5. Fruit yield per hectare (a), fruit weight (b) and survival rate (c) of ‘Aswan F₁’ watermelon plants grafted onto ‘Nun 6001 F₁’ rootstock and non-grafted ones and grown in non-sterilized soils over three experiments. (ns, *, ** and *** indicate the presence of non-significant and significant difference between grafted and non-grafted plants at * $P < 0.05$, ** $P < 0.01$ and *** $P < 0.001$)

DISCUSSION

In current study, grafted plants using all tested rootstocks, especially 'Nun 6001 F₁' had much greater foliage growth and fruit yield in comparison to non-grafted plants. In accordance with our results, Lee (1994) and Ioannou *et al.* (2001) found that grafted plants were more vigorous than self-rooted ones and had a larger central stem diameter. Salehi-Mohammadi *et al.* (2009) reported that the influence of the rootstock on the mineral content in aerial plant parts may be attributed to the physical characteristics of the root system, such as lateral and vertical development, which result in enhanced uptake of water and minerals. Rootstock 'Nun 6001 F₁' showed superior performance since it gave the highest significant fruit yield and this can be explained by the high compatibility between cv. Aswan F₁ as scion and Nun 6001 F₁ as rootstock. The low performance of other scion-rootstock compared to 'Aswan F₁'/'Nun 6001 F₁' can be justified by unsuitable graft relations that can induce undergrowth or overgrowth of the scion, which can lead to decreased water and nutrient flow through the graft union (Hartmann *et al.* 1997, Davis *et al.* 2008b, Martínez-Ballesta *et al.* 2010).

Several attempts have been made to elucidate the effects occurred in the scion as a consequence of grafting. The possibility of foreign gene transport from rootstock to scion through the vascular system was described by Molnar *et al.* (2010), Dunoyer *et al.* (2010) and Harada (2010). Also, in watermelon/squash combination, the rates of mineral ab-

sorption and cytokinin synthesis were faster than they were in the watermelon/bottle gourd and non-grafted plants, so that the plants can tolerate a heavier crop load (Yamasaki *et al.* 1994).

It was reported that the plant hormones are important endogenous factors which regulate all aspects of plant vegetative and reproductive development and thus are believed to be important player in root-shoot communication (Aloni *et al.* 2010). Plants with vigorous root systems release more cytokinins into the ascending xylem sap resulting in increased yield due to growth promotion (Aloni *et al.* 2010). Sex expression and flowering are controlled by plant hormones. The rootstock-scion combination may alter amount of hormones produced and their influence on grafted plants. In present investigation, grafted watermelon plants tend to give higher female flowers and lower male flowers comparing to non-grafted plants which affected the sex ratio in favor of non-grafted plant and this was also associated with the higher fruit yield resulted from grafted plants.

Grafting on resistant rootstocks is an advantageous alternative to soil fumigation by methyl bromide for the control of *Fusarium* wilt in watermelon production (Miguel *et al.* 2004, Yetisir *et al.* 2007). Providing resistant rootstock to susceptible scions prevents primary sources of infection, resulting in reduced disease incidence (Davis *et al.* 2008a). *Fusarium* wilt is the most widespread watermelon disease in Egypt (Ali *et al.* 1972, El-Shami 1984). Samples isolated from diseased watermelon plants collected from the experimental site generally indicated that *Fusarium oxysporum*

always showed the highest frequency. No dead plants were found in grafted plants onto 'Nun 6001 F₁' and 'Shintoza F₁', however, non-grafted plants showed severe infection with *Fusarium* wilt. The vigorous rootstocks were reported to exhibit excellent tolerance to most of serious soil borne diseases (Liu *et al.* 2009). The results of the present investigation suggest that grafting susceptible varieties onto the resistant rootstocks can be used instead of other soil treatments including chemicals, especially soil fumigation, for protection against soil-borne pathogens (Lee 1994, Liu *et al.* 2009, Ricárdez-Salinas *et al.* 2010). Wu *et al.* (2010) reported that root exudates from resistant watermelon rootstocks suppressed *Fusarium oxysporum* growth while exudates from susceptible rootstocks favored the growth.

The survival of the plants was the main factor in the determination of fruit yield per area unit, since both parameters were closely related. This result is supported by the finding of Miguel *et al.* (2004). The main factor for the 2-fold higher yield of plants grafted onto 'Nun 6001 F₁' rootstock in the three experiments was the higher plant survival as compared to the non-grafted control. In addition to plant survival, the higher fruit size in the grafted plants also made a significant contribution to the increase in yield. The higher fruit size resulted partially from the reduced vigor of the surviving non-grafted plants in the infected soils, which decreased fruit size. Fruit size was markedly higher in grafted (approx. 2.75 kg per fruit in the first two experiments and 5.0 kg per fruit in the third experiment) than

in non-grafted plants (approx. 2.25 kg per fruit in the first two experiments and 3.5 kg per fruit in the third experiment). Miguel *et al.* (2004) reported a similar effect of 'Shintoza' rootstock on fruit size in cultivar 'Queen' and 'Reina de Corazones'.

It has been reported that pH, flavor, sugar, color, carotenoids content, and texture can be affected by grafting and the type of rootstock used (Davis *et al.* 2008a) so that, the rootstock-scion combination must be carefully chosen for optimal fruit quality. The fruit size of watermelons grafted to rootstock having vigorous root systems is often significantly increased compared to fruit from intact plants. However, it is well known that other quality characteristics are influenced by rootstock. In current study, the grafting increased fruit lycopene content compared to non-grafted plants. This result was confirmed by previous reports of Proietti *et al.* (2008), Davis and Perkins-Veazie (2005). Proietti *et al.* (2008) demonstrated that the highest increase in lycopene content in grafted mini-watermelon was associated with the high potassium content in the fruit, which was observed also in tomato by Fanasca *et al.* (2006). Rising level of this health-related compound in fruit vegetables would be of great interest for human health (Rao & Rao 2007).

Grafting increases yield since plant are resistant to soil borne disease, have strong root system, and increased photosynthesis. There is a positive correlation between the vigor of grafted watermelon and the similarity of protective isozymes (peroxidase and superoxide dismutases) between grafted and ungrafted plants (Zhang *et*

al. 2006). Repeating the results observed in the first experiment during spring-summer season 2011 using the same rootstocks and tongue approach as grafting method, clearly indicated that rootstock 'Nun 6001 F₁' was more stable under different environmental conditions, giving nearly the same fruit yield during spring-summer seasons of 2010 and 2011 (the difference was 4.4%). However, 'Tetsukabuto F₁' rootstock increased the yield per plant by 34.4% in 2011 comparing with 2010. Confirming that, the rootstock 'Tetsukabuto F₁' was more affected by environment than 'Nun 6001 F₁'. Therefore, the rootstocks evaluation in the first two experiments indicated that 'Nun 6001 F₁' was better than the other two rootstocks.

Generally, grafting 'Aswan F₁' on 'Nun 6001 F₁' or 'Shintoza F₁' rootstocks caused a significant increment in fruit yield of 'Aswan F₁' scion. Meanwhile, the other rootstock (Ferro F₁) had no significant effect on fruit yield in spring-summer season of 2011. The favorable effect associated with 'Nun 6001 F₁' and 'Shintoza F₁' rootstocks might be correlated with the adequate root system structure developed by these rootstocks that may be related to the improved growth of watermelon plants. These results are supported by the previous studies which revealed that grafted watermelon, using specific rootstocks increased plant growth, fruit yield, enhanced water transport and plant nutrition (Lee 1994, Yetisir & Sari 2003, Yetisir *et al.* 2007, Han *et al.* 2009). Also, Miguel *et al.* (2004) reported that the 'Shintoza F₁' rootstock increased fruit size compared to the non-grafted plants, and improved

yield stability by decreasing the coefficient of variation to 20%. It is clear that the watermelon fruit size of plants grafted on rootstock having vigorous root systems is often significantly increased compared to the fruit from intact plants, and many growers practice grafting mainly for this reason.

In conclusion, it is believed that grafting is an effective agricultural approach to improve fruit yield and quality under adequate growth conditions, due to that the yield and quality of the shoot system, partially, depend on the root system. The fact that the positive effect of the rootstock on fruit yield and quality may be dependent on both the shoot and root genotypes makes the selection of optimum rootstocks a difficult task. Thus, if genotype such as 'Ferro F₁' has been evaluated as rootstock for watermelon cv. 'Aswan F₁' scion, the conclusion would be that the characteristics of this rootstock is not useful to increase fruit yield and quality of grafted plants depends on the shoot genotype and not on the root system of the rootstock. In Egypt, where the vegetable cultivation is still carried out mostly by traditional methods and modern cultivated techniques are limited, the grafting technique could help in solving many problems. Therefore, we consider the advantages of grafted plants, which offer increased yield and consequently higher profit, to be of value for farmers.

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WPŁYW SZCZEPIENIA NA WZROST ROŚLIN ORAZ PLON I JAKOŚĆ OWOCÓW ARBUZA

Streszczenie

Szczepienie jest alternatywną metodą ograniczania szkód w uprawach rolnych powodowanych przez patogeny glebowe oraz zwiększa tolerancję roślin na stresy abiotyczne, co z kolei zwiększa wydajność upraw. Celem badań było ustalenie, czy szczepienie może poprawić wzrost roślin i jakość owoców arbuza poprzez monitorowanie zmian wywołanych przez różne kombinacje podkładka-zraz. Arbusz (*Citrullus lanatus*) odm. Aswan F₁ zaszczipiono na pięciu podkładkach (Nun 6001 F₁, Strongtosa F₁, Tet-sukabuto F₁, Ferro F₁ i Shintoza F₁) mieszańców *Cucurbita maxima* i *Cucurbita mo-schata*. Największy wzrost wegetatywny i plon owoców uzyskano na podkładce Nun 6001 F₁, stosując metodę szczepienia przez stosowanie z języczkiem. Szczepienie spowodowało istotny spadek stosunku płci poprzez zmniejszenie liczby kwiatów męskich. Szczepienie zwiększyło istotnie zawartość likopenu w miąższu owoców, o 57% w sto-sunku do kontroli, ale nie wpłynęło na zawartość rozpuszczalnych substancji stałych (ekstraktu). Jedna trzecia nieszczepionych roślin kontrolnych obumarła, za co odpowie-dzialny był wyodrębniony patogen *Fusarium oxysporum*. Wyniki te wskazują, że szczepienie arbuza na określonej podkładce wpływa na wzrost, plonowanie i jakość owoców, a także na odporność na choroby. Szczepienie można zaproponować jako alternatywną metodę zapobiegania wędnięciu, powodowanemu przez grzyb *Fusarium*, w produkcji arbuza.