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RESEARCH PAPER

Effect of grafting on resistance to vine decline disease, yield and fruit quality in muskmelon cv. Sawadi

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تأثير التطعيم على مقاومة مرض تدهور الشمام و كمية الانتاج وجودة الثمار لصنف الشمام سوادي

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ABSTRACT. A study was conducted to evaluate graft success, resistance to vine decline disease and effect of grafting on quality and yield of muskmelon. Two field experiments, conducted in Oman, showed that muskmelon cv. Sawadi grafted on six cucurbit rootstocks gave high grafting success: 97.6-99.1% (avg. 98.6%) and 92.4-96.9% (avg. 95.3%) under field conditions in fall 2012 and spring 2013 respectively. No significant differences were observed between seasons among the six treatments and a non-grafted control in consumer preference for odor and firmness, fruit shape, flesh vitamin C, micronutrient content and TSS (sucrose %) or pH in spring 2013 ($P > 0.05$). The concentration of phosphorus and sodium significantly decreased in both seasons in all treatments in comparison to the control ($P > 0.05$). In both seasons potassium content significantly increased when Rsscih7458 and Mubyeongjangsoo rootstocks were used ($P < 0.05$). Strong Tosa rootstocks showed zero graft failure, high resistance to vine decline disease, high yield production and higher TSS (sucrose %) as compared to other rootstocks. Strong Tosa and Tetsukabuto rootstocks showed significantly higher consumer acceptance for rind color, flesh color and overall consumer acceptance in spring 2013 and was also less affected by seasonal changes. Results suggested that by grafting muskmelon cv. Sawadi some quality attributes may be improved in addition to the increased level of resistance to disease. However, additional trials are required to make final recommendations for the farming community.

KEYWORDS: Melon; grafting; soil-borne diseases; fruit quality

المستخلص: لقد أجريت هذه دراسة لتقييم نجاح التطعيم، ومقاومة الأصول لمرض تدهور و موت محصول الشمام وتأثير التطعيم على كمية الانتاج و جودة الثمار.تم تنفيذ التجارب في حقلين منفصلين في سلطنة عمان، و أظهرت النتائج أن صنف الشمام سوادي المطعوم على ستة أصول من القرعيات أعطى نجاحا كبيرا في التطعيم: حيث تراوحة نسبة التطعيم بين ٩٧,٦-٩٩,١٪ (٩٨,٦٪) و ٩٢,٤-٩٦,٩٪ (٩٥,٣٪) في ظل ظروف الحقل في خريف عام ٢٠١٢ وربيع ٢٠١٣ على التوالي. لم تظهر النتائج وجود فروق معنوية بين الستة معاملات والشاهد (الشمام الغير مطعوم) من حيث اختبار تفضيل المستهلكين للرائحة وصلابة وشكل الثمار و فيتامين C ومحتوى المواد الصلبة الذائبة (السكروز٪) أو الرقم الهيدروجيني في ربيع ٢٠١٣ (P> ٠,٠٥). وأشارت النتائج الى انخفاض تركيز الفوسفور والصوديوم بشكل ملحوظ في الثمار لكلا الموسمين في جميع المعاملات بالمقارنة مع الشاهد (P> ٠,٠٥). كما زاد محتوى البوتاسيوم زيادة كبيرة في الثمارعندما تم استخدام أصلي Rsscih٧٤٥٨ و موبي ينج سو (P >٠,٠٥). وأظهرت النتائج أن أصل السترنج توزاء أعطى نسبة٠٪ لفشل التطعيم ، وأظهر مقاومة جيدة لمرض تدهور محصول الشمام وكمية إنتاج جيدة ومحتوى مرتفع من المواد الصلبة الذائبة (السكروز٪) بالمقارنة مع غيره من الأصول. كما أشارت النتائج أن أصلي السترنج توزاء و تيتسوكابوتو حصلا على أعلى قبول لاختبار تفضيل المستهلكين من حيث لون القشرة واللون اللحم والقبول العام لاختبار تفضيل المستهلكين في ربيع عام ٢٠١٣، وكانا أيضا أقل تأثرا بالتغيرات الموسمية. عموما يمكن أن نقول أن التطعيم على الاصول المقاومة لامراض التربة أدى إلى تحسين بعض سمات جودة الثمار بالإضافة إلى زيادة مستوى المقاومة للأمراض لصنف الشمام سوادي. ومع ذلك، هناك حاجة إلى عمل تجارب إضافية لتأكيد النتائج ولتقديم التوصيات النهائية للمزارعين.

الكلمات المفتاحية: التراكم الحيوي على الأسطح المغمورة،

Introduction

Muskmelon (*Cucumis melo* L.) is one of the most economically important and widely cultivated crops in many parts of the world. In 2012, China, Turkey, Iran, Egypt and USA are the main producer of melons (FAO, 2013). In Oman, muskmelon occupied approximately 410 ha of land, with a total production of 12,500 tons in 2012 (FAO, 2013), making it among the top horticultural crops in production in the country. Production levels notwithstanding, yield in Oman is limited by several biotic and abiotic factors. Vine decline disease is the major biotic factor limiting its production, with losses exceeding 90% in several farms (Al-Mawali et al., 2013; Al-Rawahi et al., 1998; Al-Sa'di et al., 2008; Martyn, 2008). The fungus *Monosporascus*

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Table 1. Initial graft success and graft failure in the field of selected rootstocks with Sawadi muskmelon cultivar scion.

Rootstock [c]	Graft Success %[a]		Graft Failure %[b]	
	Trial#1	Trial#2	Trial#1	Trial#2
Titan	98.5	96.9	8	6.7
Tetsukabuto	97.6	96	9.3	0
Mubyeongjangsoo	98.7	96.8	0	1.7
Rsscih7458	97.9	92.4	0	5
Strong Tosa	99.1	93.3	0	0
Ezra	99.5	96.3	20	10

[a] *Graft success in nursery.*
[b] *Graft failure in field*
c Rootstock: Titan (hybrid) Ramiro Arnedo, Spain, Tetsukabuto (hybrid squash) National Seeds Production Company L.T.D-Japan, Mubyeongjangsoo (hybrid squash) Seminis® - China, Rsscih7458 (hybrid squash) Seminis® - Korea, Strong Tosa (F1 Hybrid) Syngenta Seeds – China and Ezra F1 (squash) Nickerson-Zwaan, Holland.

cannonballus is the main causal agent of melon vine decline in Oman as well as in US, Spain, Japan and many other countries. Other pathogenic fungi including *Macrophomina phaseolina*, *Fusarium* spp., *Monosporascus cannonballus*, *Phoma* spp., *Pythium* spp., *Phytophthora drechsleri*, *Rhizoctoina solani*, *Acremonium cucurbitacearum* and *Verticillum dahliae* have also been implicated in disease etiology (Aegerter et al., 2000; Al-Mawali et al., 2013; Al-Sa'di et al., 2008; Pivonia et al., 1997; Zitter et al., 1996).

The use of grafted plants for controlling soil-borne diseases has been established since the 1920s in many countries in the world including Japan and Korea (Lee, 1994). In 1990 in Japan for example, 59% of the total production area of watermelon, melon, cucumber, tomato and eggplant was associated with grafted crops (Oda, 1993, 1999). The primary purpose of grafting was originally to overcome soil-borne diseases and increase the yield of grafted crops. Objectives of grafting later expanded towards increasing tolerance to low-temperature, salt and soil wetness; improving water and nutrient uptake, increasing the plant vigor and extending harvest duration (Lee, 1994; Lee and Oda, 2003). Although in Oman grafting cucumber plants on cucurbit hybrid rootstock varieties Titan and Hercules has been shown to reduce damping-off and vine decline of cucumber (Al-Mawaali et al., 2012), commercial utilization of the technology is still in its infancy. It is also not clear whether grafting could form part of an integrated strategy to reduce vine decline of muskmelon in the country. No prior research exists on the effects of grafting on the quality of muskmelon fruit in Oman.

The main objective of this study was to characterize the level of resistance of different rootstocks to vine decline disease of muskmelon in Oman. Specific objectives included: (1) to test the compatibility of six selected cucurbit rootstocks with muskmelon cv. Sawadi; (2) to evaluate resistance of the rootstocks against vine decline disease; (3) to examine the effect of these rootstocks on yield and fruit quality of muskmelon cv. Sawadi. Knowledge in these areas will help in future management programs for vine decline disease and in improving the quality and yield of muskmelon in Oman and elsewhere.

Methodology

Plant growth and yield

The field experiment was conducted at the Agricultural Experiment Station (AES) of Sultan Qaboos University, Muscat, Oman (23.35ºN, 58.9ºE). The first trial was between October 2012 and January 2013; the second trial from February to May 2013. Tongue approach grafting was done under greenhouse conditions 12-16 days after sowing, following the method of Oda (1999). A total of 900 plants of muskmelon cv. Sawadi (scion) were grafted on six rootstocks. Graft success was recorded for all rootstocks. Treatments were distributed in the field as a completely randomized design. Soil of the field was sandy loam with pH 8.2 and soil EC 2.05 dS m^{-1}. The treatments were repeated four times with 15 seedlings in each replication. The spacing was 1m between plants, 2m between treatments and 2 m between rows. Irrigation was controlled by a Maxicom2 Central Control System (Rain Bird, CA, USA) and the water pH was 7.6 and EC was 0.3 dS m^{-1}. NPK (20:20:20) fertilizer (Kristalon, Hungary) was applied at a rate of 0.6 g per plant twice a week for the first month; thereafter 12:12:36+TE fertilizer (Kristalon, Hungary) was applied at 1.2g per plant twice a week until the end of the season (MAF, 2007; MAF, 2009). All fertilizer applications were via the irrigation system. Minimum and maximum temperatures during October, November, December 2012 and January 2013 were 20.2 to 39.9ºC, 18.9 to 34.9ºC, 13.5 to 33.4ºC, and 13.1 to 31.3ºC, respectively. Corresponding temperatures were 14.1 to 31.5ºC in February, 17.8 to 36.1ºC in March, 19.8 to 42.9ºC in April and 20.6 to 44.8ºC in May 2013. Non-grafted muskmelon seedlings (cv. Sawadi) were transplanted in the field as a control.

Vegetative growth was assessed 50 days after transplanting using 5 plants from each replicate, for each sampling event (Yetisir and Sari, 2003). Stem diameter of scion (cm) was recorded after the first node. Leaf chlorophyll was measured using four fully expanded leaves from the apex of the main stem (Yetisir and Sari, 2003). Flowering time was expressed as the percentage of plants flowering at the time when 50% plants in the treated plots had started flowering (Yetisir and Sari, 2003).

Fruits were harvested at maturity; each fruit was measured and total yield (kg) per plant was recorded. At leaf senescence, which occurred 30 to 45 days after pollination. , the effect of different rootstocks on marketable muskmelon fruits shape was analyzed by taking

Table 2. Field evaluation of the tolerance/resistance of 6 selected rootstock against vine decline disease and its effect on scion flowering, fruit number, fruit weight, leaf chlorophyll and stem diameter of Sawadi muskmelon cultivar at SQU in the fall 2012 and in the spring 2013.

Rootstock [b]	Incidence of vine decline (%)[a]		Flowering (%)[a]		Fruit No. (1000 ha^{-1})[a]		Fruit Weight (Ton ha^{-1})[a]		Chlorophyll content [a]		Stem diameter (cm)[a]	
	Trial#1	Trial#2	Trial#1	Trial#2	Trial#1	Trial#2	Trial#1	Trial#2	Trial#1	Trial#2	Trial#1	Trial#2
Ezra	66.9^{a}	51.7^{a}	44^{b}	8.1^{c}	10.6^{b}	8.9^{c}	8.1^{c}	9.7^{b}	48.7^{a}	47.4^{b}	0.82^{a}	0.71^{c}
Tetsukabuto	16^{b}	15^{b}	80^{a}	38.5^{a}	42.6^{a}	21.4^{a}	38.5^{a}	31.9^{a}	52.7^{a}	52.4^{a}	1.02^{a}	0.99^{a}
Titan	13.4^{b}	13.3^{b}	88^{a}	33.1^{ab}	38.6^{a}	19.1^{ab}	33.1^{ab}	31.8^{a}	54.6^{a}	52.6^{a}	0.95^{a}	1^{a}
Mubyeongjangsoo	9.4^{b}	13.3^{b}	97.3^{a}	38.3^{a}	43.3^{a}	17.3^{abc}	38.3^{a}	28.7^{a}	54.8^{a}	52.1^{a}	1^{a}	0.97^{ab}
Rsscih7458	4^{b}	10^{b}	97.3^{a}	24.7^{ab}	10.6^{b}	11.7 bc	24.7^{ab}	13.4^{b}	51.7^{a}	52^{a}	0.9^{a}	0.84 bc
Strong Tosa	2.7^{b}	5^{b}	86.7^{a}	42.6^{a}	43.3^{a}	20^{ab}	42.6^{a}	33.7^{a}	50.6^{a}	51.5^{a}	1.02^{a}	1.03^{a}
Control	12^{b}	16.7^{b}	94.7^{a}	43.5^{a}	48.5^{a}	22.2^{a}	43.5^{a}	32.8^{a}	53.4^{a}	50.5^{ab}	1.03^{a}	1.08^{a}

[a] *Values with the same letter in the same column are not significantly different from each other at P > 0.05(Tukey's Studentized Range test)*

[b] *Rootstock: Titan (hybrid) Ramiro Arnedo, Spain, Tetsukabuto (hybrid squash) National Seeds Production Company L.T.D- Japan, Mubyeongjangsoo (hybrid squash) Seminis® - China, Rsscih7458 (hybrid squash) Seminis® - Korea, Strong Tosa (F1 Hybrid) Syngenta Seeds - China, Ezra F1 (squash) Nickerson-Zwaan, Holland and Control (non-grafted Sawadi muskmelon cultivar) Tawoos Farm, Oman.*

fruit length and width; the circle ratio was obtained by subtracting width from length.

Response to vine decline disease

The response of grafted plants to vine decline disease was assessed by determining the percentage of plants developing typical vine decline symptoms (Al-Mawali et al., 2013). Observations on vine decline disease were taken starting 15 days after transplanting and thereafter at 15 days interval to the end of each season. The estimated inoculum density in the first trial were (1.8 ascospores g^{-1} soil, 5.5 cfua g^{-1} soil and 6.4 cfua g^{-1} soil) and in the second trial were (2.8 ascospores g^{-1} soil, 7.1 cfua g^{-1} soil and 9.5 cfua g^{-1} soil) respectively for M. cannonballus, R. solani and Pythium spp.

Fruit quality and consumer preference

Consumer preference of fruit quality attributes was performed for flavor, odor, juiciness, firmness, flesh color, rind color and overall acceptance using a 9-point hedonic scale from 1- 9 with 1 = dislike extremely and 9 = like extremely (Society of sensory professionals, 2013). In the cases of flavor, odor and juiciness, participants in panel testing were instructed to place the melon cubes between molars and to perform chewing. They assessed and recorded their score before swallowing. Firmness was assessed by applying force on the cubes between tongue and palate. They scored the preference of force required. Color was assessed by visual observation. Ninety panelists consisting of Omani students and faculty in the university completed the test in three sessions (one hour between each), six different samples of fresh fruits were used for each session. For each completed test preferences were recorded for flavor and odor (first session), juiciness and firmness (second session) and rind color, flesh color and overall acceptance (Christakou et al., 2005; Lester and Shellie, 1992). Panelists were instructed to wash the mouth once between assessments. All sessions were conducted in a climate-controlled sensory analysis booth (i.e. 22ºC room temperature, positive air pressure) and under white florescent lighting. The consumer preference test was repeated using fruits from the second field trial.

Influence of grafting on quality of muskmelon fruits

Marketable fruit total soluble solid (TSS: sucrose) was determined from 3 mature fruits from each replicate using a refractometer for sucrose (0-32%, Eclipse Brix, UK, ESR 027540). Immediately after harvest, color of rind and flesh (Hunter color value parameters brightness (L), redness (a), and yellowness (b)) of marketable fruits were measured (Minolta colorimeter CR-310, Minolta, Japan) (Crinò et al., 2007).

The pureed samples of fruit flesh were frozen at -20 Co prior to nutrient content analysis (Lee and Oda, 2003; Yetisir and Sari, 2003). Values for sugar concentration, vitamin C (mg/100g) content, N, P, K, Ca, Mg, Na and soluble protein (g/100g) content, Fe, Mn, Zn and Cu (mg/kg) content of fruit flesh were performed according to the methods of AOAC (2000).

All experimental data were analyzed using ANOVA with Tukey's Studentized Range Test to compare individual means (SAS v8, SAS Institute, Cary, NC, U.S.A).

Table 3. Effect of grafting on scion fruit pH, sucrose % and fruit shape of Sawadi muskmelon cultivar at SQU in the fall 2012 and in the spring 2013.

Rootstock [b]	pH [a]		Sucrose (%)[a]		Fruit shape [a]	
	Trial#1	Trial#2	Trial#1	Trial#2	Trial#1	Trial#2
Titan	5.7[a]	5.7[a]	14.6[a]	10.2[a]	0.6[b]	2.3[a]
Rsscih7458	5.6[ab]	5.6[ab]	13.6[a]	11[a]	0.9[ab]	1.7[a]
Strong Tosa	5.3[bc]	5.3[bc]	13[a]	11.3[a]	1.5[ab]	2.1[a]
Mubyeongjangsoo	5.2[c]	5.2[c]	12.4[a]	10.5[a]	1.3[ab]	1.6[ab]
Tetsukabuto	5.5[abc]	5.5[abc]	11.9[a]	11.9[a]	1.8[a]	1.9[a]
Ezra	5.3[bc]	5.3[bc]	10.8[a]	9.6[a]	1.5[ab]	1[a]
Control	5.3[bc]	5.3[bc]	12.7[a]	11.3[a]	1.9[a]	2.2[a]

a Values with the same letter in the same column are not significantly different from each other at P > 0.05 (Tukey's Studentized Range test) Control is non-grafted Sawadi muskmelon cultivar

b Rootstock: Titan (hybrid) Ramiro Arnedo, Spain, Tetsukabuto (hybrid squash) National Seeds Production Company L.T.D- Japan, Mubyeongjangsoo (hybrid squash) Seminis® - China, Rsscih7458 (hybrid squash) Seminis® - Korea, Strong Tosa (F1 Hybrid) Syngenta Seeds - China, Ezra F1 (squash) Nickerson-Zwaan, Holland and Control (non-grafted Sawadi muskmelon cultivar) Tawoos Farm, Oman.

Results

Plant growth and yield

Greenhouse-assessed grafting success was high for all rootstocks, ranging from 97.6 to 99.1% (avg. 98.6%) in fall 2012 and 92.4 to 96.9% (avg. 95.3%) in spring 2013. Field-assessed graft failure varied for rootstocks between 0-20% (avg. 6.2%) in fall 2012 and 0-10% (avg. 3.9%) in spring 2013. All rootstocks except Strong Tosa showed some graft failure (Table 1).

The six rootstocks exhibited variations in flowering between seasons. There were differences in earliness of flowering for the treatments. In fall 2012, flowering in Ezra rootstock plants was significantly delayed relative to other treatments; in spring 2013 all treatments with the exception of Mubyeongjangsoo were delayed relative to the non-grafted control. Plants grafted onto Ezra rootstocks had significantly lower chlorophyll content compared to grafted treatments in spring 2013 and Ezra and Rsscih7458 showed significantly smaller stem diameter compared to the non-grafted Sawadi control in spring 2013 (Table 2).

Fruit harvesting was earlier for non-grafted Sawadi plants than for any grafted plant. In fall 2012 harvesting began 52 days after sowing, 7 days before all grafted plants with the exception of those with Ezra rootstocks where harvesting started on day 66. In spring 2013 mature fruits were harvested from Sawadi plants 54 days after sowing, compared with day 63 for other grafted plants except those with Ezra rootstocks for which the harvesting started on day 65. Plants grafted onto Ezra and Rsscih7458 showed significantly lower fruit number ($P < 0.05$) compared to the non-grafted Sawadi control in fall 2012 and in spring 2013 (Table 2). Fruit weight of control was the highest in fall 2012 and Strong Tosa was the highest in spring 2013 although significantly different ($P < 0.05$) only from Ezra in fall 2012 and from Ezra and Rsscih7458 in spring 2013 (Table 2).

Response to vine decline disease

Disease incidence for all rootstocks ranged from 2.7%–66.9% (average 18.7%) in fall 2012 and 5-51.7% (average 18.1%) in spring 2013 (Table 2). Only three rootstocks maintained disease levels below control treatment - Strong Tosa, Rsscih7458 and Mubyeongjangsoo (2.7%, 4% and 9.4% in fall 2012 and 5%, 10% and 13.3% in spring of 2013, respectively) (Table 2). Ezra was apparently susceptible to highly susceptible to vine decline disease with a significant difference in incidence compared to the control in both seasons ($P < 0.05$).

There was a significant, negative correlation between disease incidence and stem diameter in fall 2012 ($R = 0.4405$, $P < 0.05$) and spring 2013 ($R = 0.4157$, $P < 0.05$); between disease incidence and chlorophyll content in fall 2012 ($R = 0.5671$, $P < 0.05$) and between disease incidence and yield in spring 2013 ($R = 0.741$, $P < 0.05$). There was a significant, positive, correlation between yield and flowering in fall 2012 ($R = 0.5885$, $P < 0.001$) and in spring 2013 ($R = 0.652$, $P < 0.001$), and between yield and stem diameter in fall 2012 ($R = 0.720$, $P < 0.001$) and in spring 2013 ($R = 0.567$, $P < 0.001$). There was no correlation between disease incidence and any of the other parameters studied.

Pythium aphanidermatum, Monosporascus cannonballus and *Rhizoctonia solani* were isolated from diseased non-grafted Sawadi plants and from plants grafted on Squash Ezra F1. Only *R. solani* was isolated from diseased plants with other rootstocks.

Fruit quality and consumer preference

TSS levels were not affected by grafting but varied between seasons (Table 3). Only the plants grafted with rootstock Titan showed a significant ($P < 0.05$) higher

Table 4. Effect of grafting on scion fruit pH, sucrose % and fruit shape of Sawadi muskmelon cultivar at SQU in the fall 2012 and in the spring 2013.

Rootstock	Hunter color values c						Consumer preference rating d						
	Rind color			Flesh color									
	L*	a*	b*	L*	a*	b*	Rind color	Flesh color	Flavor	Odor	Juiciness	Firmness	Overall acceptance
Trial 1^{a}													
Control	63.9^{a}	7.6^{a}	27.9^{ab}	80.7^{ab}	-2.7^{ab}	22.1^{a}	6.1^{a}	6.5^{a}	7.3^{a}	6.7^{a}	7.2^{a}	6.4^{a}	6.9^{a}
Strong Tosa F1	64^{a}	7.4^{a}	32.4^{a}	83.1^{a}	-5.1^{a}	23.7^{a}	6.7^{a}	7^{a}	6.3^{a}	5.9^{a}	6.1^{bc}	5.6^{a}	6.7^{a}
Mubyeongjangsoo	56.4^{ab}	7.1^{a}	29.7^{a}	82.3^{ab}	-2.7^{a}	21.1^{a}	6.8^{a}	7.1^{a}	7.1^{a}	6.3^{a}	7.2^{a}	6.3^{a}	7^{a}
Rsscih7458	57.7^{a}	6.5^{a}	29.9^{a}	83.2^{a}	-3.9^{ab}	20.4^{a}	6.5^{a}	7.3^{a}	6.6^{a}	6^{a}	7.18^{a}	6.5^{a}	7.2^{a}
Tetsukabuto	49.4^{bc}	3.8^{b}	24.9^{bc}	77^{b}	-4.8^{b}	22.3^{a}	6.6^{a}	6.8^{a}	7.3^{a}	6.5^{a}	7.7^{a}	6.7^{a}	6.7^{a}
Titan	47.7^{c}	3.3^{b}	20.9^{c}	78.3^{ab}	-4^{ab}	21.2^{a}	7.2^{a}	7.2^{a}	5^{b}	5.4^{a}	5.98^{c}	5.9^{a}	6.9^{a}
Trial 2^{a}													
Control	77.4^{a}	8.2^{a}	28.1^{ab}	81.7^{a}	-8.3^{b}	28.7^{a}	6^{b}	6.2^{b}	6.3^{ab}	5.9^{a}	6.8^{a}	6.8^{a}	6.3^{b}
Strong Tosa F1	78.4^{a}	7.5^{a}	30.4^{ab}	84.1^{a}	-6.6^{ab}	28^{a}	7.3^{a}	7.1^{a}	6.7^{ab}	6^{a}	6.6^{a}	6.6^{a}	6.9^{ab}
Tetsukabuto	77.7^{a}	8.3^{a}	33.7^{a}	83.6^{a}	-5.8^{ab}	28.6^{a}	7.1^{a}	7.2^{a}	6.8^{ab}	6.4^{a}	6.8^{a}	6.6^{a}	7.3^{a}
Titan	76^{a}	6.9^{a}	34.4^{a}	86.3^{a}	-6.5^{ab}	27.3^{a}	6.8^{ab}	7.1^{a}	5.9^{b}	5.9^{a}	6.5^{a}	6.2^{a}	6.3^{b}
Rsscih7458	75.1^{a}	7.4^{a}	31.7^{ab}	84.8^{a}	-7.5^{b}	28.5^{a}	6.6^{ab}	6.7^{ab}	6^{b}	6.4^{a}	6.9^{a}	6.6^{a}	6.7^{ab}
Mubyeongjangsoo	70^{a}	8.1^{a}	25.5 b	85.3^{a}	-4.4^{a}	27.8^{a}	7^{ab}	7^{ab}	7.2^{a}	6.5^{a}	6.5^{a}	6.8^{a}	7^{ab}

[a] *Values having on letters in common are significantly different (P > 0.05) according to Tukey's Studentized Range test*
[b] *Rootstock: Titan (hybrid) Ramiro Arnedo, Spain, Tetsukabuto (hybrid squash) National Seeds Production Company L.T.D- Japan, Mubyeongjangsoo (hybrid squash) Seminis® - China, Rsscih7458 (hybrid squash) Seminis® - Korea, Strong Tosa (F1 Hybrid) Syngenta Seeds - Chinaand Control (non-grafted Sawadi muskmelon cultivar) Tawoos Farm, Oman.*
[c] *Hunter color values (parameters L* brightness, a* redness, and b* yellowness).*
[d] *Preference ratings based on a scale when 1= Dislike extremely, 2= Dislike very much, 3= Dislike moderately, 4= Dislike slightly, 5= Neither Like nor dislike, 6= Like slightly, 7= Like moderately, 8= Like very much & 9= Like extremely. Source: (Society of sensory professionals, 2013)*

pH and different fruit shape in fall 2012 (Table 3).

Hunter color values (brightness (L), redness (a), and yellowness (b)) of fruit (rind and flesh) showed seasonal variations. Rind brightness (L), redness (a), and yellowness (b) showed a significant ($P < 0.05$) difference between control and Titan rootstock in the fall 2012. Rind brightness (L) and redness (a) showed a significant ($P < 0.05$) difference between control and Tetsukabuto rootstocks in the fall 2012. Flesh brightness (L) and yellowness (b) was not significantly different ($P > 0.05$) between fruits from non-grafted control and fruits from grafted plants in both seasons(Table 4).

Odor and firmness were not affected by grafting and showed no significant differences ($P > 0.05$) between fruits obtained from non-grafted controls and others in either fall 2012 or spring 2013. Consumer preference values were significantly ($P < 0.05$) higher for rind color and flesh color of fruit from Strong Tosa and Tetsukabuto rootstock grafted plants compared to fruits from control plants in spring 2013 (Table 4). The ratings for flavor of fruits from Titan and juiciness of fruits from Titan and Strong Tosa rootstock grafted plants was significantly ($P < 0.05$) lower than the ratings for fruits from Sawadi plants in fall 2012. Fruits from Tetsukabuto rootstock grafted plants showed significantly ($P < 0.05$) higher ratings for overall acceptance in spring 2013 compared to fruits from all other treatments (Table 4).

Significantly, positive correlations were found between consumer preference scores for juiciness and firmness in fall 2012 ($R = 0.6889$, $P < 0.01$) and spring 2013 ($R = 0.4729$, $P < 0.01$), between rind color and flesh color in fall 2012 ($R = 0.7328$, $P < 0.001$) and spring 2013 ($R = 0.5835$, $P < 0.001$), rind color with overall acceptance in fall 2012 ($R = 0.5125$, $P < 0.01$) and spring 2013 ($R = 0.5483$, $P < 0.01$) and flesh color with overall acceptance in fall 2012 ($R = 0.5143$, $P < 0.01$) and spring 2013 ($R = 0.5243$, $P < 0.01$). Hunter color values for flesh brightness (L) were positively and significantly related to consumer preference ratings for flesh color in fall 2012 ($R = 0.5165$, $P < 0.01$) and spring 2013 ($R = 0.401$, $P < 0.05$). None of the other quality attributes were significantly related.

Mineral and nutritional analysis showed some variation between seasons for some of the parameters. The seasonal effect was very clear in the case of some macroelements (N, Ca, Mg) and protein content of analyzed

Table 5. Effect of grafting on scion fruit Vitamin C, protein content, macroelements (N, P, K, Ca, Mg, Na) and microminerals (Fe, Zn, Mn and Cu) of Sawadi muskmelon cultivar commenced at SQU in the fall 2012 and in the spring 2013(Amount per 100g Fresh Product).

Rootstock [b]	**SQU Trial 1** [a]											
	Vit-C mg/100g	**Microminerals (mg/100g)**				**Macroelements (mg/100g)**						
		Fe	Mn	Zn	Cu[c]	N	P	K	Ca	Mg	Na	Protein
Control	5.3^{a}	0.02^{a}	0.001^{a}	0.02^{a}	TE	58^{b}	26^{a}	215^{b}	17^{c}	5.8^{ab}	4.8^{a}	362^{b}
Strong Tosa F1	5.4^{a}	0.02^{a}	0.0012^{a}	0.01^{a}	TE	59^{b}	10^{b}	190^{c}	20^{ab}	4^{c}	1.6^{bc}	369^{b}
Mubyeongjangsoo	5.5^{a}	0.03^{a}	0.0014^{a}	0.01^{a}	TE	73^{a}	11^{b}	230^{a}	23^{a}	4.8^{bc}	1.9^{b}	456^{a}
Rsscih7458	5.3^{a}	0.03^{a}	0.0012^{a}	0.02^{a}	TE	71^{a}	15^{b}	230^{a}	20^{ab}	5.3^{ab}	1.5^{c}	443^{a}
Tetsukabuto	6.1^{a}	0.02^{a}	0.0014^{a}	0.01^{a}	TE	74^{a}	12^{b}	220^{ab}	17^{c}	6.3^{a}	1.5^{c}	463^{a}
Titan	5.5^{a}	0.02^{a}	0.0013^{a}	0.02^{a}	TE	69^{a}	12^{a}	210^{b}	19.5^{bc}	6.3^{a}	1.1^{d}	431^{a}
	SQU Trial 2 [a]											
Control	6.6^{a}	0.03^{a}	0.001^{ab}	0.01^{a}	TE	84^{a}	23^{b}	240^{b}	16^{ab}	8^{d}	3.4^{a}	525^{a}
Strong Tosa F1	6.3^{a}	0.02^{a}	0.0007^{b}	0.01^{a}	TE	76^{bc}	17^{cd}	219^{c}	14^{c}	13^{a}	1.6^{c}	475^{ab}
Mubyeongjangsoo	9.5^{a}	0.02^{a}	0.002^{a}	0.02^{a}	TE	80^{abc}	19^{c}	250^{a}	16.3^{a}	8^{d}	2.3^{b}	500^{ab}
Rsscih7458	6.9^{a}	0.04^{a}	0.001^{ab}	0.02^{a}	TE	73^{c}	29^{a}	260^{a}	14.5^{bc}	12^{b}	3.1^{a}	456^{b}
Tetsukabuto	7.8^{a}	0.03^{a}	0.002^{a}	0.01^{a}	TE	73^{c}	14^{d}	216^{c}	17^{a}	10^{c}	1.5^{c}	456^{b}
Titan	6.5^{a}	0.03^{a}	0.002^{a}	0.02^{a}	TE	83^{ab}	18^{c}	220^{bc}	12^{d}	14^{a}	1.6^{c}	518^{ab}

[a] *Values having on letters in common are significantly different (P > 0.05) according to Tukey's Studentized Range test*
[b] *Rootstock: Titan (hybrid) Ramiro Arnedo, Spain, Tetsukabuto (hybrid squash) National Seeds Production Company L.T.D- Japan, Mubyeongjangsoo (hybrid squash) Seminis® - China, Rsscih7458 (hybrid squash) Seminis® - Korea, Strong Tosa (F1 Hybrid) Syngenta Seeds - Chinaand Control (non-grafted Sawadi muskmelon cultivar) Tawoos Farm, Oman.*
[c] *Trace elements-specifically copper*

fruits (Table 5). The vitamin C and micromineral (Fe, Zn, Mn and Cu) contents appeared not to be affected by grafting treatment and showed no significant (P > 0.05) differences in comparision to the control across seasons (Table 5). Fruit phosphorus and sodium concentrations were reduced in all grafted treatments and showed significant differences in comparision to fruits from control plants in both seasons except that phosphorus concentration was significantly (P < 0.05) higher in fruits of Rsscih7458 rootstock grafted plants compared to the control in spring 2013 (Table 5). Grafting significantly (P < 0.05) increased fruit potassium content relative to non-grafted controls for plants grafted onto Rsscih7458 and Mubyeongjangsoo rootstocks in both season (Table 5).

Discussion

There are many reported reasons why rootstock selection affects yield and scion fruit quality. Taxonomic affinity plays an important role in the success of grafting. Studies on graft compatibility have shown that many cucurbit rootstock species or cultivars, with some significant exceptions, could be used for many types of cucurbit scions (Davis et al., 2008; Lee and Oda, 2003). Different rootstocks showed varying effects on grafted plants and the difference in diameter of Cucurbita rootstock and *Cucumis* scion has been related to the survival rate of grafted plants (Traka-Mavrona et al., 2000). Incompatibility between rootstock and scion can affect undergrowth or overgrowth of the scion, leading to decreased water and nutrient flow through the graft union, causing vine decline or wilting of the grafted plant. Incompatibility can be affected by the environment, phytohormones, growth stage of rootstock and scion, physiological and biochemical characteristics and tissue and structure differences (Davis et al., 2008). Andrews and Marquez (1993) reported that graft incompatibility can be measured through failure to unite into a strong union, failure of the grafted plant to grow in a healthy manner, or premature death after grafting. Physiological incompatibility can be measured by the lack of cellular recognition, wounding responses, growth regulators, or incompatibility toxins.

In the present study, grafted Sawadi muskmelon scions showed high graft success with all tested rootstocks indicating a good affinity between the selected rootstocks and Sawadi muskmelon scion. This could be related to fortuitous selection of rootstock although many cucurbit rootstocks can be used for many different types of cucurbit scions yet taxonomic affinity does play an important role in grafting success (Traka-Mavrona et al., 2000; Lee & Oda, 2003). However, after transplanting into the field some graft failure was observed in both seasons, mainly with the Ezra rootstock. In contrast the Strong Tosa rootstock showed zero graft failure. Davis et al. (2008) have reported that after transplanting some graft failure could be related to environmental factors or poor grafting technique.

Rsscih7458, Mubyeongjangsoo and Strong Tosa rootstocks maintained average disease levels in both seasons, below average disease levels of the non-grafted control whereas Ezra rootstocks showed significantly higher disease levels in both seasons as compared to control plants. In pervious assay, this phenomena could be related to root structure that have a well-developed, vigorous root system and fast replacement of dead or infected root for withstanding vine decline (Martyn, 2008; Lee and Oda, 2003). *C. maxima*, *C. maxima x C. moschata*, and *C. moschata x C. moschata* rootstocks showed efficacy in reducing *Monosporascus* root rot vine decline disease levels in Israel (Cohen et al., 2007; Edelstein et al., 1999).

Isolations made during the current study showed the association of *P. aphanidermatum*, *M. cannonballus* and *R. solani* with declining non-grafted Sawadi plants and from plants grafted on Squash Ezra F1. Similar result was found by Al-Mawali et al. (2013) when isolation from declining muskmelons followed by pathogenicity test provided evidence that *M. cannonballus*, P. *aphanidermatum* and *R. solani*, were pathogenic to muskmelon in Oman. This result may reflect the weakness of infected plant that don't have fast replacement of dead or infected root for withstanding vine decline (Martyn, 2008 and Lee and Oda, 2003). However, some rootstocks with appropriate architectural traits are susceptible to infection by *M. cannonballus* and therefore could aid in the potential build-up of inoculum in the soil even though they typically do not support extensive perithecia development on the roots (Martyn, 2008). Only *R. solani* was isolated from diseased plants with other rootstocks.

In the current study, there was a clear effect of grafting on fruit maturity in both seasons. Harvesting from non-grafted Sawadi plants was faster in both seasons compared to grafted treatments. This could be attributed to the enhancement of undesirable physiological disorders by the rootstock such as vigorous vegetative growth, uneven maturity, and internal breakdown of fruit caused by unbalanced uptake of nitrogen and calcium into the fruit (Lee and Oda, 2003). Farmers frequently express a desire for rootstocks with less vigorous root systems, rather than the vigorous interspecific hybrid rootstocks, to obtain earlier harvests and better quality rather than higher yields (Lee and Oda, 2003). In the present study, all rootstocks used showed lower fruit number and fruit weight with the exception of Strong Tosa which gave higher fruit weights than the control in spring season 2013. This could be related to early harvesting (52-54 days) in the non-grafted control that could escape from or reduced vine decline stress on fruiting plants whilst the delay in fruit maturation (59-63 days) in grafted plant lead to increased disease stress on fruiting plants. Disease symptoms were evident in the field 62 days after transplanting grafted plants in both seasons. Strong Tosa was highly resistant to vine decline with high yield production in both seasons and should therefore be tested further with other muskmelon scions to improve production per area of cultivation.

In the present study TSS was not affected by grafting but showed variation between seasons except in the case of the Tetsukabuto rootstock grafted plants. The TSS levels of non-grafted Sawadi plants and Strong Tosa rootstock grafted plants were very high relative to other treatments. However, the TSS levels from Ezra rootstock grafted plants were exceptionally low in both seasons. This could be related to factors such as susceptibility to vine decline disease and low content of chlorophyll in leaf tissues which could result in a decrease in photosynthesis and thus a decrease in yield and fruit quality (Xu et al., 2006; Zhu et al., 2006). This result reflect the significant, negative correlation between disease incidence and chlorophyll content in fall 2012 and between disease incidence and yield in spring 2013. Similarly Rivero (2003) indicated that differences in the uptake and translocation of nutrients depend on the vigor of the aerial parts of the plant whilst as total phosphorus content in the foliar tissues of grafted plants increased there was an accompanying increase in carbohydrate content.

Consumer preference and Hunter color values of fruit (rind and flesh) showed some variation between seasons. Seasonal effects were clear in fruits from plants with the Titan rootstock in terms of the consumer preference (flavor and juiciness) and the Hunter color values (Rind brightness and redness). Previous study suggest that abnormal fruit quality has been reported in grafted melon fruit as a reduction in fruit soluble solids, persistent green color in the suture stripe, fruit fermentation, fibrous flesh and off-taste (Davis et al., 2008).

Odor and firmness were not affected by grafting and there were no significant differences between non-grafted control fruits and grafted treatments in either season. This finding is interesting since Bartoshuk and Klee (2013) pointed out that flavor quality of many fresh fruits available to consumers today certainly contributes to poor flavor. A large part of the problem is the challenge of breeding for and accurately assessing such a complex, multi-genic trait in a natural product such as a fruit. Davis et al. (2008) noted that fruit firmness could be decreased due to grafting. In the current study, consumer preferences for rind color and flesh color were significantly higher for Strong Tosa and Tetsukabuto rootstock grafted fruits than for the non-grafted control in spring 2013. This was mainly due to the higher than expected preference matching with color, flavor and odor as shown in Table 4. Fruits from Tetsukabuto rootstock grafted plants showed the highest overall acceptance rating in spring 2013 which reflect the positive effect of the rootstock on fruit of grafted muskmelon plant.

The uptake and translocation of ions, photosynthesis, plant hormones and alkaloids can be influenced by rootstocks or the grafting method used. Vigorous rootstocks can show an increase in the uptake of water and minerals as compared to own rooted plants. The increase in water absorption in grafted plants may cause a dilution of ion concentration in xylem sap that affects the absorption and translocation of ions such as phosphorus, nitrogen, magnesium and calcium and microelements including iron and boron (Lee and Oda, 2003). Rivero (2003) reported that differences in the foliar N and Na content can lead to differences in yield.

In the present study, nutrient content showed some variation between seasons for some parameters. This may have been caused by unbalanced uptake of water and minerals such as nitrogen and calcium into the fruit. Seasonal effects were also very clear for some macroelements (N, Ca, Mg) and protein content of fruit. Vitamin C, pH and microminerals (Fe, Zn, Mn and Cu) were not affected by grafting and showed no significant differences between treatments in either season. Phosphorus and sodium concentrations were reduced in all grafted treatments and showed significant differences with the non-grafted control plants in both seasons. The potassium content of grafted Sawadi fruits increased when Rsscih7458 and Mubyeongjangsoo rootstocks were used and showed significant differences with non-grafted controls in both season that is good for human due to increase the nutritional value of muskmelon fruit.

Conclusion

All rootstocks used with the Sawadi scion showed high graft success. Strong Tosa rootstocks showed zero graft failure, high tolerance or resistance to vine decline disease, with significantly higher yield production and higher TSS values compared to other treatments in both seasons. Titan rootstock grafted plants were highly affected by seasonal changes and gave variable results across seasons for many of the assessed parameters. The use of Ezra rootstocks should be approached with some caution as they appear to be susceptible to infection by *M. cannonballus* and could therefore increase inoculum in the soil even though they typically do not support extensive perithecia development on the roots. Strong Tosa and Tetsukabuto rootstocks showed significantly higher consumer acceptance for rind color and flesh color and Tetsukabuto showed significantly higher rating for overall consumer acceptance in spring season. Strong Tosa and Tetsukabuto are recommended for further testing with other muskmelon scions to improve yield and fruit quality.

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