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RESEARCH PAPER

Effect of rootstock on muskmelon cultivar reaction to vine decline disease and yield under arid conditions

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تأثير الأصول على استجابة أصناف الشمام لمرض التدهور والانتاج تحت الظروف الجافة

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Abstract. *Monosporascus cannonballus*, *Rhizoctonia solani* and *Pythium aphanidermatum* are the main causal agents of muskmelon vine decline disease in Oman. This study was conducted to examine the response of six cucurbit rootstocks grafted on four muskmelon scions to the causal agents and fruit quality and quantity. The response of 10 day old Palmira seedlings to artificial inoculation with *R. solani* pathogen alone revealed more damage to muskmelon seedling whereas *P. aphanidermatum* and *M. cannonballus* caused less damage when inoculated singly but more disease severity index when combined with *R. solani*. Artificial inoculation of different rootstocks produced significantly no damping-off and very low vine decline disease severity index on Mubyeongjangsoo, Titan, Tetsukabuto, Rsscih7458, Ezra and Strong Tosa rootstocks. All rootstocks produced high grafting success and low graft failure with the four selected muskmelon cultivars. Rootstocks enhanced early harvesting of grafted Tamara but had no effect on other scions. Fruit shape was almost not significantly affected by grafting except Samit grafted on Strong Tosa and Caramel grafted on Mubyeongjangsoo produced significantly different fruit shapes compared to ungrafted controls in the spring 2013 trial. Fruits from both grafted Shahd and Tamara showed no significant differences in rind brightness, redness and yellowness from the control. Various effects of rootstock were found on harvesting, fruit number and weight, chlorophyll content, and stem diameter of the scion. Rootstocks enhanced early harvesting and increased fruit number and fruit weight in grafted Tamara scions. There was no significant effect of grafting on fruit TSS. The study shows positive effects of grafting on tolerance to vine decline and on fruit quality and yield.

Keywords: Grafting; melon vine decline; fruit quality; integrated disease management.

المستخلص: لقد أجريت هذه دراسة لتقييم نجاح التطعيم، ومقاومة الأصول لمرض تدهور و موت محصول الشمام وتأثير التطعيم على كمية الانتاج وجودة الثمار.تم تنفيذ التجارب في حقلين منفصلين في سلطنة عمان، وأظهرت 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 وموبي 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 وتيتسوكابوتو 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: التطعيم، الشمام، مرض التدهور، جودة الثمار، الادارة المتكاملة للمرض

Introduction

China, Turkey, Iran, Egypt and USA were the main producers of melons in the world in 2012 (FAO, 2014). In Oman, about 410ha were cultivated, with a total production of 12,500t in 2012 (FAO, 2014). Despite the high demand, these crops suffer from several diseases caused by different fungi, bacteria and viruses. Muskmelon vine decline is considered the factor most limiting muskmelon production and losses have been reported to exceed 90% (Al-Rawahi et al., 1998; Al-Sa'di et al., 2008a). The disease also affects production elsewhere (Zitter et al., 1996; Martyn, 2008). Monosporascus cannonballus is frequently the primary pathogen of late-season vine decline (Zitter et al., 1996; Robinson and Decker-Walters, 1997; Martyn, 2008) although other pathogens including *Macrophomina phaseolina*, *Fu-*

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sarium spp., *Phoma* spp., *Pythium* spp., *Phytophthora drechsleri*, *Rhizoctonia solani*, *Acremonium cucurbitacearum* and *Verticillum dahliae* have been implicated (Zitter et al., 1996; Pivonia et al., 1997; Aegerter et al., 2000; Al-Sa'di et al., 2011b; El-Kolaly and Abdel-Sattar, 2013). In Oman *Monosporascus cannonballus*, *Rhizoctonia solani* and *Pythium aphanidermatum* have been reported as causal agents of muskmelon vine decline (Al Mawaali et al., 2013).

The use of grafted plants for controlling soilborne diseases has been established for many decades (Lee, 1994) with the additional benefit of increasing yields and tolerance to low-temperature, salt and soil wetness, improving water and nutrient uptake and plant vigor, and extending harvest duration (Lee, 1994; Lee and Oda, 2003). In Oman the use of grafting is increasing. Al-Mawaali et al. (2012) reported that grafted cucumber plants (on hybrid rootstock varieties Titan and Hercules) showed no symptoms of damping-off and vine decline and also produced a significant increase in yield.

Benefits in terms of disease reduction notwithstanding, issues remain to be resolved before grafting can be widely adopted within a commercial arena. Incompatibility between rootstock and scion (Andrews and Marquez, 1993; Davis et al., 2008) 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. Graft incompatibly 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.

No previous research has been reported evaluating the potential of grafting under the harsh and arid conditions of Oman. It is not clear whether grafting could reduce vine decline disease. Furthermore, little is known about the effects of grafting on muskmelon fruit quantity and quality.

The main objective of this study was to characterize the response of rootstocks and to evaluate the technique as part of a management system for vine decline disease of muskmelon. Specific objectives were to examine the response of six cucurbit rootstocks to the pathogens causing vine decline of muskmelon in in vivo and field and the effect of the rootstocks on quality and yield of muskmelon.

Materials and methods

Optimization of inoculation protocol

Ten seeds of muskmelon Palmira were sown in sterile soil (91% sand) in 15cm pots. Seedlings were thinned to five per pot after emergence. Five day old cultures of Pythium aphanidermatum and Rhizoctonia solani and 8 day old Monosporascus cannonballus colonies, all on PDA (25gl-1) were blended in 50ml sterile distilled water (SDW) and 50ml of the inoculum was added to the soil surface in each pot when seedlings had reached 10 days old. The three causal agents were used in different treatment combinations. In control pots a 90mm disc of macerated PDA blended in 50ml SDW was used as a negative control (Table 1). Pots were held at 33±2oC day and 23±2oC night in a completely randomized design under glasshouse conditions, with a 12hr day length. Five pots were used for each treatment and the experiment was repeated once. Plants were irrigated daily with 100ml of water (0.3dS/m and pH 8.1) and 1% aqueous (20:20:20) NPK fertilizer (Kristalon, Hungary) was applied once per week. Percent plants exhibiting damping-off and/or wilt symptoms were recorded every 2d after inoculation. After 28d, the soil was gently washed from the roots and disease on hypocotyls (H), primary roots (R1R) and secondary roots (R2R) was assessed. Isolation from roots and crowns of five randomly selected plants was done on PDA to confirm infection by the inoculated pathogen (Tsay and Bor-Kai Tung, 1995; Bruton et al., 2000).

Disease ratings for H, R1R and R2R were as follows: 1 = healthy with no lesions or discoloration, 2 = slight discoloration, 3 = moderate discoloration and/or with lesions, 4 = moderate disintegration or up to 25% root mass reduction compared with controls, and 5 = severe maceration, with more than 50% root mass reduction and/or plant wilt. A disease severity index (DSI) showing the extent of damage on muskmelon was calculated as follows: DSIj = (Hj + R1Rj + R2Rj)/3 (Bruton et al., 2000).

Response of rootstocks to pathogen inoculation

From the results of the optimization test the combined inoculum of *M. cannonballus* + Rhizoctonia solani + *P. aphanidermatum* was used to test rootstock response. Positive-inoculated and negative non-inoculated muskmelon Palmira seedlings were included as controls. Twenty five seeds of each positive-inoculated and negative non-inoculated muskmelon Palmira and of each of the 11 tested rootstock were sown and distributed in five 15cm pots with sterile soil (91% sand). Inoculation procedures and post-inoculation conditions were as described above. Five pots were used for each treatment and the experiment was repeated once. Irrigation, fertilization, disease incidence and disease assessments were as described previously.

Field trials and effects on fruit yield and quality

Based on the results of the seedling trials and research reported elsewhere (Al-Mawaali et al., 2013), rootstock varieties Tetsukabuto, Mubyeongjangsoo and Strong Tosa were used for grafting with the commercial muskmelon cultivars Samit, Shahd, Caramel and Tamara. Field experiments were carried out at two locations with a history of severe muskmelon decline attributed to *M. cannonballus*, *Rhizoctonia solani* and Pythium spp. including *P. aphanidermatum* (Al-Sa'di et al., 2008a;

Figure 1. Stunting of plant growth and gradual death or wilt of the leaves.

Figure 2. Slight to moderate discoloration and disintegration of the hypocotyl tissue with loss of root mass.

Al-Mawaali et al., 2013). Site 1 has sandy soil with pH 8.1 and EC 6.29 dS/m (Barka, 23° 39. 189′ N and 57° 46.268′ E) while site 2 has sandy loam soil with pH 8.2 and EC 2.05 dS/m (Al-Seeb, 23° 35.925′N and 58° 9.799′E). Inoculum potential of the soils of the two experimental sites was estimated through dilution plate technique before graft transplant. The estimated inoculum densities were 8.2 ascospores g^{-1} soil, 9.6 cfua g^{-1} soil and 19.7 cfua g^{-1} soil for *M. cannonballus*, *R. solani* and *Pythium* spp., respectively at site 1 and 2.6 ascospores g^{-1} soil, 6.5 cfua g-*1* soil and 7.3 cfua g-*1* soil) for *M. cannonballus*, *R. solani* and Pythium spp., respectively at site 2.

Under greenhouse conditions tongue approach grafting was done 12-16 days after scion and rootstock seeds were sown (Oda, 1999) and graft success was recorded. 150 plants of each muskmelon scion were selected after successful grafting on each rootstock. Non-grafted seedlings of each muskmelon cultivar were included in each design as a control. Field trial design was completely randomized at site 2 and a complete block design at site 1; in both cases using four replicates with 15 seedlings in each replication. Distance between plants was 1 m with 2 m between treatments and 2 m between rows. Irrigation was for 15 min, twice per day for two weeks, then for 20 min for weeks 3-4 and 25 min until the end of the season. The irrigation water had pH 7.7 & EC 0.91 dS/m at site 1 and pH 7.6 & EC 0.3 dS/m at site 2) . NPK (20:20:20) fertilizer was applied at a rate of 0.6 g per plant twice a week for the first month. NPK (12:12:36) + TE was applied at a rate of 1.2 g per plant twice a week starting at week five until final harvest (MAF, 2007; MAF, 2009). Minimum and maximum temperatures during February - May 2013 at site 1 were 13.4 and 43.3 °C, respectively, and it was 15.9 and 42.9 °C, respectively during September - December 2013 at site 2. The survival rate of grafted plants was measured after 15 days and expressed as percent of total grafted plants. Flowering time was expressed as the number of days from sowing to first male and female flower appearance (Yetisir and Sari, 2003). The numbers of dead plants and those with damping-off or wilt symptoms were recorded every 7d for 90d.

Vegetative growth was sampled 50 d after transplanting. From each replicate 5 plants were measured for each sampling event (Yetisir and Sari, 2003). Stem diameter of scion (cm) was recorded after first node (Leonardi and Romano, 2004). Leaf chlorophyll was measured (Konica Minolta Sensing, Japan, ESR 81423044) using the 4th ful-

Table 1. Pathogen inoculum combinations used to incite vine decline disease on muskmelon Palmira.

Inoculum combination	Dose
Monosporascus cannonballus	50 ml (Monosporascus) + 100 ml PDA
M. cannonballus + *Pythium aphanidermatum*	50 ml (Monosporascus) + 50 ml (Pythium) + 50 ml PDA
M. cannonballus + *Rhizoctonia solani*	50 ml (Monosporascus) + 50 ml (Rhizoctonia) + 50 ml PDA
M. cannonballus + *R. solani* + *P. aphanidermatum*	50 ml (Monosporascus) + 50 ml (Rhizoctonia) + 50 ml (Pythium)
R. solani + *P. aphanidermatum*	50 ml (Rhizoctonia) + 50 ml (Pythium) + 50 ml PDA
P. aphanidermatum	50 ml (Pythium) + 100 ml PDA
R. solani	50 ml (Rhizoctonia) + 100 ml PDA
Control	150 ml PDA

PDA: Difco potato-dextrose agar

Table 2. Response of 10 days old muskmelon Palmira seedlings to artificial inoculation with different pathogen combinations.

Inoculum ++	Spring 2013				
	Incidence	Mean damage rating rank *			
	(%)	RH	R1R	R2R	DSI ‡
Pa + Rs	96 a	122.9 ab	114.9 ab	115.8 ab	4.9 a
Rs	92 a	156.1 a	154.1 a	153 a	4.8 a
Mc + Pa + Rs	88 a	96.7 b	96.2 b	95.2 b	4.7 a
Mc + Rs	80 ab	119.1 ab	111.6 ab	113 ab	4.5 a
Mc + Pa	80 ab	114.6 ab	124.3 ab	128.1 ab	4.3 a
Pa	68 ab	98.2 b	100.4 b	95.6 b	4.0 a
Mc	32 bc	74.6 b	85 b	82.6 b	3.2 a
Control	0	21.7 c	17.5 c	20.5 c	1.1 b
	Fall 2013				
Rs	48 a	126.2 a	125 a	125.4 ab	4.4 a
Pa	44 ab	102.1 ab	101.6 a	102 ab	3.0 ab
Mc+Pa	36 ab	113.9 ab	111.1 a	110.9 ab	3.5 ab
Pa+ Rs	28 ab	129.5 a	129.1 a	129 a	3.4 ab
Mc + Pa + Rs	12 ab	124.7 a	122.1 a	121.8 ab	2.9 ab
Mc + Rs	8 ab	115.4 ab	117.7 a	117.6 ab	3.3 ab
Mc	0	66.9 bc	78.5 a	77.2 b	2.4 bc
Control	0	25.2 c	18.8 b	20.2 c	1.0 c

++ Mc - *M. cannonballus*, Pa - *P. aphanidermatum*, Rs - Rh*izoctonia solani*.
* Values with the same letter in the same column are not significantly different from each other at P < 0.05 (Tukey's Studentized Range for disease incidence and DSI; Gwet's (2010) method of mean separation for RH, R1R and R2R).
‡ DSI - disease severity index (Bruton et al., 2000).

ly expanded leaf from the apex of the main stem (Yetisir and Sari, 2003).

Fruit number and weight (kg) were recorded for each plant (Leonardi and Romano, 2004). At leaf senescence, which occurred 30-45 d after pollination, the effect of rootstock on marketable fruit quality, and fruit shape was analyzed by assessing fruit length, width and circle ratio. Fruit total soluble solids (TSS) was determined for three ripening fruits per replicate by refractometer (Eclipse Brix Refractometer, UK) (Lee and Oda, 2003; Yetisir and Sari, 2003). Immediately after harvest, rind color (Hunter color values: brightness (L), redness (a), and yellowness (b)) of marketable fruits were measured (Minolta colorimeter CR-310, Minolta, Serial No. 79581006, Japan) (Crinò et al., 2007).

Statistical analysis

Differences between treatment means for parametric data were analyzed using ANOVA and Tukey's Studentized Range test under GLM analysis (SAS v8, SAS Institute, Cary, NC, U.S.A). Treatment mean ranks for non-parametric data were compared using Kruskal-Wallis analysis with means separated using the method of Gwet (2010). Correlation analysis was used to test consistency between trials.

Results

Inoculation protocol optimization and assessment of rootstock response to vine decline pathogens

The combination of *P. aphanidermatum* and *R. solani* showed the highest disease incidence (96%) and DSI (4.9) in the first trial with a significant difference from the control and *M. cannonballus* inoculation alone (P < 0.05). *R. solani* caused the highest damage to hypocotyls, primary roots and secondary roots in second trial and was second in the first trial, with a significant difference from the control (P < 0.05) (Table 2). Disease incidence and DSI arising from different combinations of the three pathogens showed moderate discoloration with lesions to moderate maceration of hypocotyl tissue and moderate discoloration to severe maceration of primary roots and secondary roots with no significant difference between the different combinations and all showed a significant difference from the control (P < 0.05) (Table 2).

None of the tested rootstocks showed damping-off or mortality with the exception of Sharad and Connecticut Field which showed significant levels of mortality in both trials following inoculation with a mixture of selected virulent pathogens (Table 3). Mubyeongjangsoo, Titan, Tetsukabuto, Rsscih7458, Ezra and Strong Tosa showed slight tissue discoloration and lower DSI values in the first and second trials with a significant difference compared with the positive, inoculated muskmelon control and Sharad and Connecticut Field rootstock (P > 0.05) (Table 3). The above-ground symptoms were stunting of plant growth and gradual death or wilt of the leaves (Fig. 1). This was associated with water-soaked areas in the hypocotyl of seedlings, after which the seedlings collapsed. Slight to moderate discoloration and disintegration of the hypocotyl tissue, primary roots and secondary roots with loss of root mass were found in Sharad, Connecticut Field and the positive inoculated muskmelon control (Fig. 2), with no significant differences between these three treatments in the first trial (P > 0.05) (Table 3).

Evaluation of selected cucurbit rootstocks against vine decline disease under field condition and their effect on fruit quality and yield of muskmelon

High graft success was found between Mubyeongjangsoo rootstock and Samit muskmelon scion (98.4%),

Table 3. Assessment of 11 different rootstocks for resistance/tolerance to the pathogens causing vine decline disease in muskmelon crop in Oman, with plant damage rating (RH= hypocotyl; R1R= primary root; R2R= secondary roots).

Treatment[+]	Spring 2013				
	Disease incidence (%)	Mean damage rating rank[*]			DSI[‡]
		RH	R1R	R2R	
Negative control (-)	0	101.5 [a]	38.7 [a]	82.6 [a]	1.02 [a]
Tetsukabuto	0	119.6 [a]	71.8 [ab]	108.2 [abc]	1.22 [ab]
Titan	0	113.5 [a]	95.4 [ab]	108.2 [abc]	1.26 [ab]
Mubyeongjangsoo	0	113.5 [a]	119 [abc]	92.9 [ab]	1.3 [abc]
Rsscih7458	0	131.6 [a]	165.6 [c]	103.1 [abc]	1.5 [abcd]
Strong Tosa	0	125.6 [a]	156.3 [bc]	123.6 [abc]	1.52 [abcd]
Ezra	0	131.6 [a]	160.8 [bc]	159.4 [abc]	1.64 [bcd]
Baromashi	0	167.7 [ab]	160.4 [bc]	175.3 [bc]	1.78 [cd]
Squash T1	0	246 [b]	156.3 [bc]	154.3 [ab]	1.9 [d]
Dinero F1	0	164.1 [ab]	198.8 [cd]	185.4 [cd]	1.94 [d]
Sharad	4 [ab]	175.8 [abc]	260.4 [d]	270.3 [de]	2.78 [e]
Connecticut field	4 [ab]	267.9 [d]	274.3 [d]	287.8 [e]	3.2 [e]
Positive control	8 [b]	260.6 [cd]	261.3 [d]	267.8 [de]	2.94 [e]
		Fall 2013			
Negative control (-)	0	87.0 [a]	54.5 [a]	75.0 [a]	1.01 [a]
Tetsukabuto	0	136.4 [abc]	148.7 [bc]	143.2 [abcd]	1.5 [abc]
Titan	0	117.9 [ab]	157.3 [bc]	137.5 [abcd]	1.46 [abc]
Mubyeongjangsoo	0	117.9 [ab]	115.5 [ab]	114.8 [ab]	1.34 [ab]
Rsscih7458	0	136.4 [abc]	153 [bc]	120.4 [abcd]	1.46 [abc]
Strong Tosa	0	164 [abcd]	178.2 [bc]	191.1 [bcde]	1.78 [bcd]
Ezra	0	192.1 [bcd]	141.9 [ab]	143.2 [abcd]	1.62 [bcd]
Baromashi	0	161.2 [abcd]	125.3 [ab]	112.3 [ab]	1.44 [abc]
Squash T1	0	204 [bcd]	179.4 [bc]	188.6 [bcd]	1.9 [cde]
Dinero F1	0	216.8 [cd]	158.6 [bc]	157.8 [abcde]	1.74 [bcd]
Sharad	0	139.3 [abc]	236.4 [cd]	244.4 [ef]	2.1 [de]
Connecticut field	4 [a]	231.6 [d]	279.2 [d]	283.7 [f]	2.86 f
Positive control	20 [b]	214.4 [cd]	190.8 [bcd]	207.1 [def]	2.39 [ef]

[*a] Values with the same letter in the same column are not significantly different at $P < 0.05$ (Tukey's Studentized Range for disease incidence and DSI; Gwet's (2010) method of mean separation for RH, R1R and R2R). Low values for RH, R1R and R2R are indicative of low level disease.

[‡] DSI - disease severity index (Bruton et al., 2000).

[+] Titan (hybrid) Ramiro Arnedo, Spain, Tetsukabuto (hybrid squash) National Seeds Production Company L.T.D- Japan, HYB Squash (T1) Seminis, China, Mubyeongjangsoo (hybrid squash) Seminis® - China, Rsscih7458 (hybrid squash) Seminis® - Korea, Strong Tosa (F1 Hybrid) Syngenta Seeds – China Melon Dinero (F1 Hybrid) Syngenta Seeds, Peru, Ezra F1 (squash) Nickerson-Zwaan, Holland, Baromashi (Pumkin) Lal Teer Seeds, Bangladesh, Connecticut field (pumpkin) Bonanza Seeds, USA Bottle Gourd (F1 Sharad) United Genetics, India and Control (Palmira hybrid muskmelon cultivar) Nickerson-Zwaan, the Netherlands.

Strong Tosa rootstock with Shahd and Caramel (97.4% and 98.4% respectively) and lower graft failure with Tamara, Shahd and Samit (0%, 2.5% and 3.3%, respectively), and Tetsukabuto with Tamara (97.5%) and lower graft failure with Caramel (1.1%) (Table 4).

Disease incidence showed variation between rootstock and scion at both sites. Disease incidence for all rootstocks with different scions ranged from 0-20% (mean = 6.7 %) at site 1 and 2.2-24.5 % (mean = 11.5%) at site 2 (Table 5). Mubyeongjangsoo rootstock grafted with Samit, significantly lowered the disease level compared to Tetsukabuto and Strong Tosa in site 1 ($P < 0.05$). Tetsukabuto and Strong Tosa rootstocks grafted with Shahd significantly reduced disease level at site 2 compared to the control treatment (non-grafted Shahd) ($P < 0.05$) and Mubyeongjangsoo grafted with Caramel significantly lowered disease level at site 1 compared to the control treatment (non-grafted Caramel) ($P < 0.05$). All rootstocks grafted with Tamara maintained average disease levels at both sites and below the average disease

Table 4. Initial graft success and failure in the field for selected rootstocks with different muskmelon scions.

Scions + Rootstock [a]	Greenhouse graft success (%)		Field graft failure (%)	
	Spring 2013	Fall 2103	Spring 2013	Fall 2103
Samit + Tetsukabuto	94	98.8	6.7	2.2
Samit + Mubyeongjangsoo	98	98.8	10.0	0.0
Samit + Strong Tosa	95	95.2	6.7	0.0
Shahd + Tetsukabuto	95	98.8	10.0	0.0
Shahd + Mubyeongjangsoo	95	98.8	6.7	0.0
Shahd + Strong Tosa	96	98.8	3.3	2.2
Caramel + Tetsukabuto	95	98.8	0.0	2.2
Caramel + Mubyeongjangsoo	95	100.0	3.3	0.0
Caramel + Strong Tosa	98	98.8	6.7	4.5
Tamara + Tetsukabuto	95	100.0	10.0	0.0
Tamara + Mubyeongjangsoo	96	95.2	3.3	2.2
Tamara + Strong Tosa	95	96.4	0.0	0.0

[a] Rootstock: **Tetsukabuto** (hybrid squash) National Seeds Production Company L.T.D- Japan, **Mubyeongjangsoo** (hybrid squash) Seminis® - China and **Strong Tosa** (F1 Hybrid) Syngenta Seeds – China; Scions: **Samit muskmelon** (hybrid) Asgrow, USA, **Shahd** (hybrid) Trust Seeds, Jordan, **Caramel** (hybrid) Clause, China and **Tamara** (hybrid) Hollar Seeds, USA.

levels of the control (non-grafted Tamara), showing significant differences when compared to Mubyeongjangsoo and Strong Tosa at site 1 and Tetsukabuto at site 2 ($P < 0.05$) (Table 5).

The three rootstocks caused variation in flowering with different scions at both sites (Table 5). Flowering of

Table 5. Initial graft success and failure in the field for selected rootstocks with different muskmelon scions. Values with the same letter in the same column are not significantly different from each other ($p > 0.05$, Tukey's Studentized Range test).

Treatments [+]	Incidence (%)		Flowering (%)		Fruits (10^3 ha^{-1})		Fruit weight (t ha^{-1})		Chlorophyll		Stem diam. (cm)	
	Site 1	Site 2	Site 1	Site 2	Site 1	Site 2	Site 1	Site 2	Site 1	Site 2	Site 1	Site 2
Samit control	3.3^{c}	26.7^{a}	6.7^{b}	31.1^{a}	24.7^{a}	20.2^{a}	36.6^{a}	31.2^{ab}	49.8^{b}	49.7^{a}	0.88^{a}	1.2^{a}
Samit + Tets	13.3^{b}	22.2^{ab}	56.7^{a}	35.6^{a}	21.0^{ab}	21.0^{a}	34.3^{ab}	38.6^{a}	49.4^{b}	50.0^{a}	0.65^{b}	1.2^{a}
Samit + Mub	3.3^{c}	24.5^{ab}	63.3^{a}	31.1^{a}	18.4^{b}	18.7^{a}	33.4^{ab}	34.3^{ab}	55.5^{a}	53.0^{a}	0.70^{b}	1.0^{b}
Samit + ST	20.0^{a}	15.5^{b}	53.3^{a}	33.3^{a}	17.2b	16.3^{a}	28.6^{b}	28.4^{b}	48.9^{b}	50.7^{a}	0.73^{b}	1.1^{ab}
Shahd control	0.0	11.1^{a}	36.7^{a}	48.9^{a}	27.7^{a}	21.7^{a}	38.0^{a}	26.9^{a}	52.7^{ab}	54.2^{a}	0.83^{a}	0.73^{a}
Shahd + Tets	6.7^{b}	2.2^{b}	36.7^{a}	26.7^{a}	23.9^{ab}	22.7^{a}	32.2^{ab}	31.6^{a}	51.6^{ab}	52.9^{a}	0.68^{b}	0.88^{a}
Shahd + Mub	16.7^{a}	6.7^{ab}	43.3^{a}	40.0^{a}	20.9b	20 .0^{a}	24.7^{b}	30.5^{a}	55.5 a	57.0^{a}	0.68^{b}	0.95^{a}
Shahd + ST	3.3^{b}	2.2^{b}	56.7^{a}	35.6^{a}	25.0^{ab}	19.7^{a}	35.4^{a}	29.5^{a}	50.8^{b}	55.9^{a}	0.83^{a}	0.8^{a}
Caramel control	10.0^{a}	4.5^{b}	3.3^{b}	71.0^{a}	30.1^{a}	22.4^{a}	38.6^{a}	28.7^{a}	47.2^{a}	52.2^{b}	0.90^{a}	1.1^{a}
Caramel + Tets	6.7^{ab}	8.9^{ab}	56.7^{a}	57.8^{b}	28.7^{a}	18.5^{b}	34.1^{a}	21.8^{a}	47.2^{a}	57.7^{a}	0.88^{a}	1.0^{a}
Caramel + Mub	3.3^{b}	8.9^{ab}	56.7^{a}	75.6^{b}	28.1^{a}	21.0ab	33.4^{a}	25.6^{a}	50.8^{a}	56.1^{ab}	0.88^{a}	1.0^{a}
Caramel + ST	3.3^{b}	15.5^{a}	50.0^{a}	73.3^{a}	28.9^{a}	19.7ab	30.2^{a}	22.0^{a}	48.1^{a}	56.1^{ab}	0.93^{a}	1.1^{a}
Tamara control	6.7^{a}	15.5^{a}	23.3^{a}	31.1^{a}	19.7b	13.6^{b}	28.6^{ab}	17.0^{a}	55.2^{ab}	53.1 c	0.83^{b}	0.9^{a}
Tamara +Tets	3.3 ^{ab}	8.9 ^{b}	40.0^{a}	40.0 ^{a}	18.3b	16.5^{a}	26.6^{ab}	23.0^{a}	54.5^{ab}	58.9^{ab}	1 .0^{a}	0.83^{b}
Tamara + Mub	0.0	11.1^{ab}	36.7^{a}	48.9^{a}	22.1^{ab}	16.5^{a}	25.6^{b}	19.4^{a}	58.2^{a}	60.2^{a}	0.85^{b}	0.93^{ab}
Tamara + ST	0.0	11.1^{ab}	20.0^{a}	46.7^{a}	26.3^{a}	16.7^{a}	33.2^{a}	17.8^{a}	53.5^{b}	55.8^{bc}	0.9^{ab}	0.95a

[+] Rootstock: **Tetsukabuto** (hybrid squash) National Seeds Production Company L.T.D- Japan, **Mubyeongjangsoo** (hybrid squash) Seminis® - China and **Strong Tosa** (F1 Hybrid) Syngenta Seeds – China; Scions and control non-grafted muskmelon cultivars: **Samit** muskmelon (hybrid) Asgrow, USA, **Shahd** (hybrid) Trust Seeds, Jordan, **Caramel** (hybrid) Clause, China and **Tamara** (hybrid) Hollar Seeds, USA.,

Table 6. Effect of grafting on scion fruit Total Soluble Solids (TSS), shape and rind color (Hunter color values) of different muskmelon cultivar scions. Values with the same letter in the same column are not significantly different from each other ($p > 0.05$, Tukey's Studentized Range test).

Treatments b	TSS (%)a		Fruit shape a		Rind - Hunter color values a					
					Brightness		Redness		Yellowness	
	Site 1	Site 2	Site 1	Site 2	Site 1	Site 2	Site 1	Site 2	Site 1	Site 2
Samit F1 (Cont)	8.6^{ab}	9.5^{a}	3.4^{a}	3.2^{a}	81.9^{a}	79.3^{b}	11.2^{a}	9.6^{a}	37.5^{a}	36.6^{a}
Samit F1 + Tets	8.9^{a}	10.1^{a}	3.0^{ab}	3.2^{a}	83.7^{a}	87.5^{a}	8.0^{b}	8.6^{a}	34.5^{a}	38.2^{a}
Samit F1 + Mub	7.7^{b}	9.2^{a}	3.1^{ab}	3.6^{a}	77.7^{a}	82.9^{ab}	6.2 c	6.9^{a}	35.9^{a}	38.8^{a}
Samit F1 + ST F1	9.0^{a}	8.9^{a}	2.9^{b}	4.2^{a}	77.7^{a}	80.0^{b}	6.7^{bc}	6.8^{a}	37.8^{a}	42.2^{a}
Shahd F1 (Cont)	10.2^{a}	11.0^{a}	1.4^{a}	1.1^{a}	72.8^{a}	77.1^{a}	8.3^{ab}	9.8^{a}	39.1^{a}	43.9^{a}
Shahd F1 + Tets	9.7^{a}	10.4^{a}	1.3^{a}	1.6^{a}	78.2^{a}	72.8^{a}	9.9^{ab}	11.2^{a}	39.0^{a}	37.7^{a}
Shahd F1 + Mub	10.2^{a}	11.5^{a}	1.0^{a}	1.2^{a}	74.7^{a}	72.3^{a}	10.3^{a}	10.7^{a}	35.5^{a}	37.0^{a}
Shahd F1 + ST F1	10.0^{a}	11.1^{a}	1.1^{a}	1.3^{a}	76.2^{a}	81.0^{a}	7.7^{b}	9.0^{a}	35.0^{a}	40.5^{a}
Caramel F1 (Cont)	11^{ab}	10.9^{a}	2.5^{a}	1.7^{a}	79.4^{a}	79.7^{ab}	9.8^{a}	13.6^{a}	38.4^{a}	41.4^{b}
Caramel F1 + Tets	12 .0^{a}	10.4^{a}	1.8^{ab}	1.6^{a}	79.1^{a}	81.9^{ab}	8.8^{ab}	10.3^{ab}	40.1^{a}	42.6^{b}
Caramel F1+ Mub	9.7^{b}	9.5^{a}	1.3^{b}	1.3^{a}	77.0^{a}	87.8^{a}	7.3^{b}	8.3^{b}	40.1^{a}	53.1^{a}
Caramel F1 + ST F1	10.3 b	9.5^{a}	1.8^{ab}	1.6^{a}	79.6^{a}	74.9 b	7.2^{b}	5.8^{c}	38.9^{a}	42.7^{b}
Tamara F1 (Cont)	9.1^{a}	10.2^{ab}	2.0^{a}	0.8^{a}	71.4^{a}	74.0^{a}	4.4^{c}	5.8^{b}	34.6^{a}	30.7^{a}
Tamara F1 +Tets	9.4^{a}	10.5^{ab}	2.1^{a}	1.3^{a}	74.9^{a}	74.4^{a}	5.6^{bc}	6.9^{b}	34.9^{a}	35.2^{a}
Tamara F1 + Mub	9.6^{a}	11.0^{a}	1.6^{a}	0.9^{a}	78.2^{a}	79.6^{a}	7.9^{a}	7.5^{b}	36.0^{a}	37.8^{a}
Tamara F1 + ST F1	8.7^{a}	9.7^{b}	1.5^{a}	1.1^{a}	76.6^{a}	80.6^{a}	7.3^{ab}	12.1^{a}	37.8^{a}	41.2^{a}

[+] Rootstock: **Tetsukabuto** (hybrid squash) National Seeds Production Company L.T.D- Japan, **Mubyeongjangsoo** (hybrid squash) Seminis® - China and **Strong Tosa** (F1 Hybrid) Syngenta Seeds – China; Scions and control non-grafted muskmelon cultivars: **Samit** muskmelon (hybrid) Asgrow, USA, **Shahd** (hybrid) Trust Seeds, Jordan, **Caramel** (hybrid) Clause, China and **Tamara** (hybrid) Hollar Seeds, USA.,

the control showed no significant differences with grafted Shahd and Tamara on all rootstocks ($P > 0.05$).

There was a clear effect of grafting on fruit maturity of Tamara at both sites. Harvesting of grafted Tamara was advanced at both sites compared to non-grafted treatments (day 62 in spring to day 59 in fall for grafted plants, day 65 to day 64 for controls). There was no clear effect of grafting on fruit maturity of Samit, Shahd and Caramel at either site.

Most rootstocks caused variations in fruit number and fruit weight at both sites among the seasons with significant differences between the control and other treatments. Grafted Tamara on Strong Tosa showed significantly higher fruit number than non-grafted Tamara at both sites and with Tetsukabuto and Mubyeongjangsoo at site 2 (13.6 on control, 16.5, 16.5 and 16.7 (1000 ha-1), respectively) ($P < 0.05$) (Table 5). A significant reduction in fruit weight was observed when Samit muskmelon was grafted on Strong Tosa compared to control (non-grafted Samit) at site 1 (28.6 and 36.6 ton ha-1 on control, respectively) ($P < 0.05$) and between the control (non-grafted Shahd) and Shahd grafted on Mubyeongjangsoo at site 1 (38 and 24.7 ton ha-1, respectively) (Table 5).

Only Mubyeongjangsoo increased chlorophyll content of leaves of all grafted cultivars with significant differences in some seasons with some cultivars. Stem diameter of the control (non-grafted Samit) was significantly bigger than grafted Samit at site 1 and with the Mubyeongjangsoo rootstock at site 2 ($P < 0.05$) (Table 5).

There was no effect of grafting on grafted Shahd and Tamara fruit TSS, fruit shape and Hunter color values. TSS levels were not significantly affected by grafting for Samit, Shahd, Caramel and Tamara scions with Tetsukabuto, Mubyeongjangsoo and Strong Tosa rootstocks (Table 6). Fruit shape was significantly affected only when Samit was grafted onto Strong Tosa and when Caramel was grafted onto Mubyeongjangsoo compared to the control plant fruits at site 1, in spring 2013 ($P < 0.05$) (Table 6).

A significant negative correlation was found between leaf chlorophyll content and stem diameter at site 1, in spring 2013 ($r = 0.542$, $P < 0.05$) and between leaf chlorophyll content and disease incidence in the spring 2013 ($r = 0.594$, $P < 0.05$). A significant positive correlation was found between yield and stem diameter in spring 2013 ($r = 0.513$, $P < 0.05$) and in fall 2013 ($r = 0.741$, $P < 0.01$). No correlations were found between disease incidence and any of the other parameters studied.

Hunter color values of fruit rind showed no significant difference for rind brightness between control

treatments and grafted Shahd, Caramel and Tamara. Whereas fruits from Samit grafted onto Tetsukabuto revealed significantly higher rind brightness from the control treatment at site 2 in fall 2013 ($P < 0.05$) (Table 6). There was no significant difference for rind redness between controls of Shahd at both sites among the seasons ($P > 0.05$). Rind redness of grafted Samit fruits showed a significant reduction compared to the control in spring 2013, and showed a significant increase in fruits from Tamara grafted onto Strong Tosa at both sites among the seasons ($P < 0.05$). Rind yellowness showed no significant differences between control treatments and grafted Samit, Shahd and Tamara on all rootstocks in both seasons ($P > 0.05$). Only fruits from Caramel grafted on Mubyeongjangsoo significantly increased rind yellowness compared with control non-grafted Caramel and this was at site 2, in fall 2013 only ($P < 0.05$) (Table 6).

Discussion

In Oman *M. cannonballus, R. solani* and *P. aphanidermatum* are causal agents of vine decline of muskmelon (Al-Mawaali et al., 2013). In the current study the response of 10-day old Palmira seedlings to artificial inoculation with *R. solani* pathogen alone revealed more damage to muskmelon seedling. Nearly the same result was found by Al-Mawaali et al. (2013) when the responses of 10-day and 20-day old muskmelon seedlings (cv. Palmira F1) to artificial inoculation with fungi isolated from declining muskmelon plants showed that *R. solani* produce the highest average of disease severity index with 2.55 DSI. Artificial inoculation with *P. aphanidermatum* and *M. cannonballus* caused less damage when inoculated singly but more disease severity index when combined with *R. solani*. Similar results were found by Pivonia et al. (1997) and El-Kolaly and Abdel-Sattar, (2013) where a combination of *P. aphanidermatum* and *M. cannonballus* showed higher mortality than was caused by either pathogen alone; the combination of *P. aphanidermatum* with *M. cannonballus* and *R. solani* resulted in higher mortality than caused by each pathogen alone. However, future studies should be undertaken to compare the response of different pathogens interacting with different inoculation times.

Grafting was initially developed to overcome soil borne diseases and to increase the yield of grafted crops, to encompass tolerance of low-temperature, salt and soil wetness, improve water and nutrient uptake, increase plant vigor, extending harvesting time duration and in melon crop should ideally be resistant to Fusarium oxysporum, *M. cannonballus*, Melon necrotic spot virus (MNSV) and Meloidogyne spp. (Lee, 1994; Lee and Oda, 2003). In the present study, the assessment of rootstock response to vine decline pathogens showed that Mubyeongjangsoo, Titan, Tetsukabuto, Rsscih7458, Ezra and Strong Tosa rootstocks showed no damping-off or mortality and showed resistance or tolerance when inoculated with a mixture of *M. cannonballus*, *R. solani* and *P. aphanidermatum* and showed the lowest DSI values. Previously, Al-Mawaali et al. (2012) reported that Titan and Hercules rootstocks reduced damping-off and wilt disease and also resulted in a significant increase in the yield of the grafted cucumbers.

In this study more evaluations were done for three rootstocks (Mubyeongjangsoo, Tetsukabuto and Strong Tosa) and four muskmelon scions. The results showed that all rootstocks produced high graft success and lower graft failure with the scions with higher graft success and lower graft failure of some rootstock to some scions. This could indicate a good affinity related to fortuitous selection. Traka-Mavrona et al. (2000) and Lee and Oda (2003) reported that taxonomic affinity plays an important role in the success of grafting with some significant exceptions and could reflect the ability of these rootstocks to affect a strong union with the scion providing more efficient uptake of water and minerals. Field evaluation for the response to disease produced different reactions of rootstocks with scion cultivars among seasons. However some rootstocks significantly lowered the disease level in field condition compared to other rootstocks which produced better graft success and lower graft failure with different scions. This may suggest a good potential adaptation of those rootstocks to environmental factors such as drought tolerance and could be related to the root structure which is believed to be a main factor in the grafting of susceptible melons onto tolerant and/or resistant Cucurbita spp. rootstocks for control of *M. cannonballus* (Martyn, 2008; Lee and Oda, 2003). Similarly, the use of C. maxima, C. maxima x C. moschata, and C. moschata x C. moschata rootstocks against Monosporascus in Israel, shows their efficacy as a method in the management of this disease (Edelstein et al., 1999; Cohen et al., 2007). This has been correlated to a well-developed, vigorous root system that quickly replaces dead or infected roots (Martyn, 2008; Lee and Oda, 2003). However, low graft success and high graft failure after transplanting in some rootstocks could be related to environmental factors or lack of skill of the grafter as reported in pervious study by Davis et al. (2008).

In the current study, the three rootstocks decreased stem diameter of grafted Samit and produced various effect on other scions and caused variations in flowering and fruit maturity in both seasons. Although, Strong Tosa, Tetsukabuto and Mubyeongjangsoo increased fruit number and fruit weight in grafted Tamara that could reflect the significant positive correlation between stem diameter and yield at both sites. This could be collated to the effect of grafting on the amount of hormones produced and their influence on scion organogenesis. Davis et al. (2008) reported that watermelon grafted onto bottle gourd showed early formation of female flowers but when grafted onto pumpkin, bottle gourd and wax gourd flowering was delayed.

Only Tetsukabuto produced higher average fruit weight at both sites on grafted Samit; the same rootstock showed a decrease in fruit number and fruit weight for Shahd and Caramel. This may be related to taxonomic affinity, to the strength of the enhancement of undesirable physiological disorders by the rootstock (Lee and Oda, 2003; Leonardi et al., 2003). However, in pervious assay, many farmers used a rootstock with a less vigorous root system rather than interspecific hybrid rootstocks to obtain earlier harvest and better quality rather than high yield (Lee and Oda, 2003). There was no clear effect of grafting on fruit maturity of Samit, Shahd and Caramel at either site.

Only Mubyeongjangsoo enhanced chlorophyll content of leaves of all scions with a significant difference in some seasons with some cultivars. Three types of rootstock effects on melon color values of fruit rind, fruit shape and TSS (sweetness) have been demonstrated (increase, no change and decrease). This can be due to the effect of different production environments, type of rootstock/scion combination used, and harvest date (Davis et al., 2008). In the present study, various effects of grafting were observed in color values of fruit rind that could reflect the effect of grafting on the amount of hormones produced and their influence on scion organogenesis. Fruit shape almost was not affected by grafting for Shahd and Tamara with Tetsukabuto, Mubyeongjangsoo, and Strong Tosa. However, fruits obtained from grafted Samit plants on Strong Tosa and from Caramel grafted on Mubyeongjangsoo were significantly different in shape from control plant fruits in spring 2013. Also TSS was not affected by grafting in Samit, Shahd, Caramel and Tamara scions with Tetsukabuto, Mubyeongjangsoo, and Strong Tosa rootstocks. This result could be related to a good uptake and translocation of water and nutrient from soil. On the other hand, a reduction in uptake of water and nutrient from soil can cause a decrease in chlorophyll content in leaves and this causes a decrease in photosynthesis and is reflected in a decrease in yield and fruit quality (Rivero, 2003; Hu et al., 2006; Xu et al., 2006).

It can be concluded that following artificial inoculation, no damping-off and very low disease severity index was observed in Mubyeongjangsoo, Titan, Tetsukabuto, Rsscih7458, Squash Ezra and Strong Tosa rootstocks. An effect of rootstock was found on harvesting, fruit number and weight, chlorophyll content, and stem diameter of the scion. Rootstocks enhanced early harvesting and increased fruit number and fruit weight in grafted Tamara scions. There was no significant effect of grafting on fruit flesh TSS. Strong Tosa F1 Hybrid, Tetsukabuto (hybrid squash), Mubyeongjangsoo (hybrid squash) can be used as rootstocks for Tamara F1 muskmelon. Future research is also required to examine more cucurbit rootstocks for muskmelon against vine decline disease resistance and for the improvement of fruit yield and quality. Strong Tosa F1 Hybrid, Tetsukabuto (hybrid squash), Mubyeongjangsoo (hybrid squash) rootstocks showed high resistance to *M. cannonballus* and *P. aphanidermatum* but were infected by Rhizoctonia solani. Integrated disease management tactics including cultural management, sanitation, tillage, crop rotation and chemical management using Tachigaren (Hymexazol)), metam sodium (Vapam™), fluazinam (Frownicde™ ISK, Japan) and Fludioxinil (Cannonball™, Syngenta) should be tested in Oman for their compatibility with grafting as part of an integrated disease management package. Strong Tosa F1 Hybrid, Tetsukabuto (hybrid squash), Mubyeongjangsoo (hybrid squash) rootstocks may be tested with other scions such as watermelon for resistance against vine decline disease and cucumber for resistance against damping-off and wilt diseases.

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