Phytopathologia Mediterranea (2013) 52, 3, 457–465

RESEARCH PAPERS

Etiology, development and reaction of muskmelon to vine decline under arid conditions of Oman

Qais Saif AL-MAWAALI[1], Abdullah Mohammed AL-SADI[2*], Fahad AlJulanda AL-SAID[2] and Michel Leonard DEADMAN[2]

[1] Directorate General of Agricultural & Livestock Research, Ministry of Agriculture, PO Box 50, A'Seeb 121, Oman
[2] Department of Crop Sciences, Sultan Qaboos University, P O Box 34, Al Khoud 123, Oman

Summary. Muskmelon vine decline is considered the most important factor limiting muskmelon production in Oman. This study was conducted to characterize incidence, development, causal agents and response of muskmelon cultivars to this disease. A survey showed that incidence of the disease ranged from 0 to 15% (mean 5%) in spring 2011, 1 to 80% (mean 18%) in autumn 2011 and 0 to15% (mean 10%) in spring 2012. Isolations from 168 affected plants yielded *Pythium aphanidermatum* (56% of diseased plants sampled), *Fusarium* spp. (46%), *Monosporascus cannonballus* (27%), *Rhizoctonia solani* (22%) and *Macrophomina phaseolina* (1%). In pathogenicity tests, *R. solani, M. cannonballus* and *P. aphanidermatum* were found to be pathogenic to muskmelon. In another experiment over three seasons, *M. cannonballus, P. aphanidermatum* and *R. solani* were consistently isolated from muskmelon plants on a weekly basis from 14 days after sowing until the end of the season. However, symptom development only began with the onset of fruiting, which suggests that fruiting stress may be a factor in vine decline disease development. Field assessment of 11 muskmelon cultivars showed that 'Shahd F1' was one of the cultivars least susceptible to vine decline and was relatively high yielding. This is the first record of *M. cannonballus* as a causal agent of muskmelon vine decline in Oman.

Key words: *Monosporascus, Pythium*, wilt, root rot.

Introduction

Cucurbits are among the most widely cultivated crops, grown in subtropical, tropical and temperate regions. Watermelon, muskmelon and other cucurbits are among the most important vegetable crops in terms of production and area of cultivation in Oman (FAO, 2012), an arid country in which agriculture is heavily dependent on water from underground aquifers. In this country, muskmelon is the third most important vegetable crop in terms of production and area of cultivation, with a total production of 11797 tons in 2010 (FAO, 2012).

Muskmelon vine decline is the most limiting factor to muskmelon production in Oman. Losses due to this disease have been reported to exceed 90% in several farms in Oman and elsewhere (Al-Rawahi *et al*., 1998; Al-Sa'di *et al*., 2008a; Martyn, 2008). Development of fungicide resistance, rapid degradation of fungicides in soil, delayed inactivation of pathogen inoculum and the low efficacy of cultural and biocontrol methods make vine decline control challenging (Deadman *et al*., 2006; Al-Sa'di *et al*., 2008b; Al-Hinai *et al*., 2010; Al-Sadi *et al*., 2011a; Al-Sadi, 2012).

Monosporascus cannonballus Pollack & Uecker is the primary pathogen causing late-season vine decline of melon and watermelon in most areas of the world where these crops are grown (Martyn, 2008). Other pathogens associated with the disease in muskmelon and other cucurbits include *Acremonium cucurbitacearum* Alfaro-Garcia, W. Gams & Garcia-Jim, *Fusarium* spp., *Macrophomina phaseolina* (Tassi) Goid, *Phoma* spp., *Phytophthora drechsleri* Tucker, *Pythium* spp., *Rhizoctonia solani* Kühn and *Verticil-*

Corresponding author: A.M. Al-Sadi
Fax: +96 899424633
E-mail: alsadi@squ.edu.om

ISSN (print): 0031-9465
ISSN (online): 1593-2095

lium dahliae Kleb (Gubler and Davis, 1996; Pivonia *et al.*, 1997; Aegerter *et al.*, 2000; Al-Sadi *et al.*, 2010, 2011a,b). In Oman, limited-scale surveys in some farms attributed vine decline to infection by *Fusarium oxysporum* Schlecht, *F. solani* (Mart.) Sacc., *Pythium aphanidermatum* (Edson) Fitzp., *P. deliense* Meurs and *P. splendens* Hans Braun (Moghal *et al.*, 1993; Al-Rawahi *et al.*, 1998; Al-Sa'di *et al.*, 2008a). It is therefore not clear whether pathogenic fungi associated with vine decline of muskmelon in other parts of the world could also be the causal agents for the disease under the arid conditions of Oman.

Pivonia *et al.* (1997) have shown that incidence of vine decline is affected by fruiting stress. However, little is known about the relationship between fungal infection of root systems, growth stage of muskmelon and severity of vine decline. In addition, several muskmelon cultivars are grown in Oman, but little is known about their yield and susceptibility to this disease. Lack of this information constitutes a barrier to effective management of vine decline.

The main objective of this study was to characterize vine decline and evaluate the reaction of muskmelon cultivars to the disease in Oman, to provide a basis for future management programmes for the disease in Oman and other arid areas of the world. The specific objectives of this study were: i) to characterize pathogens associated with vine decline of muskmelon in Oman; ii) to investigate the relationship between growth stages of muskmelon, fungi associated with roots and severity of vine decline; and iii) to evaluate the reaction of selected muskmelon cultivars to vine decline.

Materials and methods

Survey and collection of samples

A survey was initiated in muskmelon-growing regions in Oman in order to assess incidence of vine decline and to determine the pathogens that are associated with the disease. The survey covered the six muskmelon growing governorates in Oman: Batinah South, Batinah North, Sharqiya South, Sharqiya North, Dhofar and Buraimi. The survey was conducted during the spring and autumn of 2011 and the spring of 2012. Incidence of the disease was estimated by determining the number of declining muskmelon plants, at the fruiting stage, out of the total grown. Samples of roots and crowns were collected from 168 declining muskmelon plants from six to 17 farms per governorate, except that only two farms in Sharqiya North and one farm in Dhofar were sampled. Isolation of fungi and oomycetes from plant samples was on potato dextrose agar (PDA, Oxoid, Basingstoke, UK) amended with 10 mg L^{-1} rifampicin and 200 mg L^{-1} ampicillin, as described by Al-Sadi *et al.* (2011b).

Identification of fungal pathogens

Identification of the isolated fungi to the species level was achieved using morphological characteristics (Plaats-Niterink, 1981; Barnett and Hunter, 1998; Leslie and Summerell, 2006). This was further confirmed for most of the isolates using sequences of the internal transcribed spacer region of the ribosomal DNA (ITS rDNA). DNA extraction, amplification by polymerase chain reaction and sequencing were as described by Al-Sadi *et al.* (2011c).

Pathogenicity test

Two randomly selected isolates of each of the five fungi and oomycetes which were recovered from diseased muskmelon plants were inoculated on healthy 10 and 20-d-old seedlings (d after sowing). Ten seeds of cv. Palmira F1 were sown in autoclaved field soil (91% sand) placed around the circumference of each 15 cm diam. pot. Seedlings were thinned to five plants per pot after emergence. Pots were inoculated with 5-d-old *P. aphanidermatum*, *R. solani* or *M. phaseolina*, 8-d-old *M. cannonballus* or 10-d-old *F. solani* colonies growing on PDA (25 g L^{-1}). The entire 90 mm diam. fungal colony, with PDA, of one isolate was placed in the center of each pot and covered with a 10 mm layer of the autoclaved field soil (Tsay and Tung, 1995; Al-Mawaali *et al.*, 2012). In each control pot, a 90 mm diam. disc of PDA was used instead of the fungal colony. Five pots were used for each treatment (two isolates × two seeding ages at inoculation) and the experiment was repeated once. Pots were held at 30 ± 1°C day and 18 ± 1°C night temperature in a completely randomized design in a research glasshouse with day length of 12 h. Plants were irrigated daily with 100 mL of water, and 1% aqueous NPK (20:20:20) fertilizer (Kristalon, Hungary) was used instead of water once per week. The percentage of plants exhibiting damping-off and wilt symptoms was recorded every 2 d after inoculation.

After 28 d, the soil was gently washed from the roots of the plants and disease on hypocotyls (H), primary roots (R1R) and secondary roots (R2R) was assessed. Isolation of fungi from roots and crowns of five randomly selected plants from each treatment was done on PDA to confirm infection by the inoculated fungus. Root dry weights of surviving plants were determined after drying roots at 63°C for 34–35 h.

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 disintegration, with more than 50% root mass reduction and/or plant wilt. A disease severity index (DSI) was calculated as follows: $DSI_j = (H_j + R1R_j + R2R_j)/3$ (Bruton *et al.*, 2000).

Influence of growth stage of muskmelon and fungal infection on vine decline

To study the relationship between growth stages of muskmelon, fungi associated with roots and appearance of decline symptoms, the following experimental approach was followed. An experiment was conducted in a field (23.35°N, 58.9°E) on the Agricultural Experiment Station at Sultan Qaboos University. The field had a previous history of severe decline symptoms of muskmelon (Al-Sa'di *et al.*, 2008a), which was attributed to several fungi, including *Pythium* species. The first trial was from February to May 2011. Muskmelon seeds (cv. Joyce-F1) were sown directly in the field, with 1 m spacing between plants. Irrigation was controlled by a Maxicom^2 Central Control System (Rain Bird, CA, USA) that monitored weather conditions and controlled the irrigation system as weather conditions required. NPK fertilizer (as above) at a rate of 0.6 g per plant was applied twice a week for the first month, and 1.2 g per plant was applied twice a week until the end of the season. Fertilizer application was through the irrigation system. Samples of roots and crowns were collected on a weekly basis from five randomly selected plants for 11 weeks. Isolation and identification of fungi to the species level were done as described above. The number of declining plants was recorded and converted to percentage incidence.

The experiment was repeated twice, in September 2011 and in February 2012, using the same treatments in the same land, except that 1.2 g of NPK (12: 12: 36) + trace elements (Kristalon, Hungary) per plant was applied from one month until the end of the season in thste experiments.

Reaction of muskmelon cultivars to vine decline

Eleven cultivars of muskmelon commonly grown in Oman (see Table 1) were evaluated for yield and reaction to vine decline in the spring of 2011, in the autumn of 2011 and again in the spring of 2012. The minimum, average and maximum temperatures were 12.7, 28.0 and 45.5°C in the spring seasons (2011 and 2012) and 13.8, 27.9 and 43.2°C in the autumn season (2011). The experiment was conducted in the same field at Sultan Qaboos University. A total of 64 seeds for each muskmelon cultivar were sown directly in the open field using a randomized block design. There were four blocks for each treatment with 16 seedlings in each block. The distance between plants was 1 m and between rows was 2 m. There was a 2 m distance between treatment blocks. Fertilization using NPK (12: 12: 36) + trace elements was as described above for each growing season. Repetition of the experiment in the following seasons was in the same field but using a different design (randomizing blocks and treatments in the field).

The number of seedlings showing death, damping off or wilt symptoms was recorded every 7 d for

Table 1. Sources of 11 muskmelon cultivars used in this study.

Cultivar	Source
Ananas	Bonanza Seeds, U.S.A
Ananas F1	Vilmorin Seeds, France
Caramel F1	Clause, China
Joyce-F1	Select Seed, U.S.A
Palmira F1	Nickerson-Zwaan, the Netherlands
Raneen F1	Enza Zaden, the Netherlands
Samit F1	Asgrow, U.S.A
Shahd F1	Trust Seeds, Jordan
Super Sweet F1	Trust Seeds, Jordan
Tamara F1	Hollar Seeds, U.S.A
Punjab Sunehri	Plantsman, India

90 d. Number of fruit and fruit weight were recorded for each plant. Fruit total soluble solids (TSS) were determined using a refractometer (Bellingham and Stanley Ltd, London, UK) for 12 randomly selected fruits per cultivar, while root dry weight was determined for 20 plants per cultivar after drying roots at 63°C for 34–35 h. Samples of roots and crowns were collected from declining plants. Isolation and identification of fungi to the species level were achieved as described above.

Statistical analyses

Means were separated and analyzed using Tukey's Studentized Range test (SAS v8). Correlation analysis was also used to investigate the relationship between fruit number, fruit weight, TSS and root dry weight.

Results

Incidence and distribution of muskmelon vine decline

The survey in different regions and seasons in Oman revealed that muskmelon vine decline was present in all the surveyed regions. Incidence of the disease ranged from 0 to 15% (mean 5%) in spring 2011, 1 to 80% (mean 18%) in autumn 2011 and 0 to 15% (mean 10%) in spring 2012. Incidence of the disease varied among the surveyed regions (Table 2).

Pathogens associated with vine decline

Isolations from roots and crowns of declining muskmelon plants yielded *P. aphanidermatum* (56% of diseased plants sampled), *R. solani* (22%), *Fusarium* spp. (46%), *M. cannonballus* (27%) or *M. phaseolina* (0.6%) (Table 2). All pathogens which were recovered from the roots were recovered from the crown areas of sampled plants, with the exception for *M. phaseolina*. Five *Fusarium* species were recovered from muskmelon roots, with *F. solani* being the most common. Other *Fusarium* species included *F. chlamydosporum* Wollenw. & Reinking var. *fuscum* Gerlach, *F. equiseti* (Corda) Sacc, *F. acutatum* Nirenberg & O'Donnell, and *F. brachygibbosum* Padwick (data not presented). With the exception of *M. phaseolina*, all fungi were widely distributed in the regions assessed (Table 2).

Pathogenicity test

Inoculation of 10- and 20-d-old muskmelon seedlings with five fungal and oomycete species showed that *P. aphanidermatum*, *M. cannonballus* and *R. solani* resulted in varying levels of mortality in the inoculated seedlings (Table 3). The above-ground symptoms were stunting of plant growth and gradual death or wilt of the leaves. This was associated with water-soaked areas in the hypocotyls, after which seedlings collapsed. *Rhizoctonia solani*, *P. aphanidermatum* and *M. cannonballus* caused moderate discoloration and disintegration of the hypocotyl tissues,

Table 2. Incidence (%) of vine decline and frequency of recovery (%) of fungi from declining muskmelon plants in six regions (governorates) in Oman. Values in columns represent percentage of total number of plants sampled from which each fungus was recovered.

Governorate (No. of plants sampled)	Disease incidence (avg. %)	*Rhizoctonia solani*	*Fusarium* spp.	*Pythium aphanidermatum*	*Monosporascus cannonballus*	*Macrophomina phaseolina*
Batinah North (70)	5.1	11.4	45.7	70	25.7	1.4
Batinah South (40)	15.3	20	57.5	50	25	0
Sharqiya South (30)	8.5	33.3	46.7	53.3	43.3	0
Sharqiya North (10)	8.0	0	0	70	20	0
Buraimi (15)	4.4	73.3	26.7	13.3	13.3	0
Dhofar (3)	0	0	100	20	0	0
Overall (168)	7.6	21.8	45.9	55.9	26.5	0.6

Table 3. Responses of 10-d and 20-d-old muskmelon seedlings (cv. Palmira F1) 28 days after artificial inoculation with fungi isolated from declining muskmelon plants.

Fungal species	10-d-old seedlings[a]						20-d-old seedlings[a]					
	Trial #1			Trial #2			Trial #1			Trial #2		
	Incidence	DSI[b]	RDW	Incidence	DSI[b]	RDW	Incidence	DSI[b]	RDW	Incidence	DSI[b]	RDW
Pythium aphanidermatum	28 a	2.4 a	0.10 ab	4 a	1.5 c	0.088 a	10 a	1.8 bc	0.062 b	24 a	2.2 b	0.12 ab
Monosporascus cannonballus	6 b	2.6 a	0.12 ab	6 a	2.3 b	0.122 a	0	2.3 ab	0.036 b	4 b	2.8 a	0.11 ab
Rhizoctonia solani	0	1.6 b	0.10 ab	2 a	3.3 a	0.084 a	8 ab	2.6 a	0.046 b	2 b	2.7 ab	0.08 b
Fusarium solani	0	1.06 c	0.09 ab	0	1.1 c	0.102 a	0	1.07 c	0.044 b	0	1.2 c	0.09 b
Macrophomina phaseolina	0	1.03 c	0.08 b	0	1.2 c	0.07 a	0	1.1 c	0.04 b	0	1.07 c	0.09 b
Control	0	1.02 c	0.15 a	0	1.03 c	0.136 a	0	1.06 c	0.104 a	0	1.02 c	0.21 a

[a] Values in each column accompanied by the same letter not significantly different ($P<0.05$; Tukey's Studentized Range test).
[b] DSI is the disease severity index (Bruton *et al.*, 2000) and RDW is root dry weight. Incidence of the disease represents the percentage of declining plants out of the total of 25 inoculated per isolate, while RDW represents root dry weight (g). Zero values were not included in the statistical analysis. Data for the two isolates of each pathogen were combined for analysis as there were no significant differences between isolates of each fungus.

primary roots and secondary roots. These pathogens caused disease and mortality on 10-d-old and 20-d-old seedlings, with *P. aphanidermatum* being significantly more aggressive than some of the fungi evaluated in trial No. 1 (10-d-old plants) and trial No. 2 (20-d-old plants) (Table 3). No damping-off or wilt symptoms were observed on control plants nor on plants inoculated with *F. solani* or *M. phaseolina* during the experimental period. *Pythium aphanidermatum, M. cannonballus* and *R. solani* were re-isolated from all symptomatic roots of artificially inoculated plants. In addition, there was no significant difference in mortality of muskmelon seedlings between the two isolates of the each fungal species used for inoculation (data not presented).

Influence of plant growth stage and fungal infection on vine decline

Pythium aphanidermatum, M. cannonballus and *R. solani* were isolated from symptomless roots and crowns of muskmelon plants from d 14 to d 86 (fruit harvest); *M. cannonballus* and *R. solani* were significantly more commonly isolated than *P. aphanidermatum* in the autumn of 2011 and the spring of 2012 ($P<0.05$) (Figure 1).

Fruit ripening started 56 d after planting. Plant mortality started almost at the same time as fruit ripening in the three seasons, and increased with time to reach 16% after 86 d in spring 2011, 37% in fall 2011 and 32% in spring 2012 (Figure 1).

Reaction of muskmelon cultivars to vine decline

Muskmelon plants in the field started to develop crown lesions within 50 to 55 d of sowing. Severe disintegration of the root systems and vine decline were first observed about 65 to 75 d after sowing.

Evaluation of the 11 cultivars for reaction to vine decline over three seasons showed variation among the cultivars and seasons. Disease incidence for all cultivars ranged from 8 to 19% (mean 14%) in spring 2011, 10 to 37% (mean 20%) in autumn 2011 and 20 to 54% (mean 31%) in spring 2012 (Table 4). Disease incidence on cv. Shahd F1 was 11% in the spring and autumn of 2011 and 20% in the autumn of 2012, which was less than the average values of 14%, 20% and 31%, respectively, for all cultivars combined (Table 4). All the other cultivars showed variation in susceptibility to vine decline. *Pythium aphanidermatum*, *M. cannonballus*, *R. solani, Fusarium* spp., and *M. phaseolina* were isolated from declining plants.

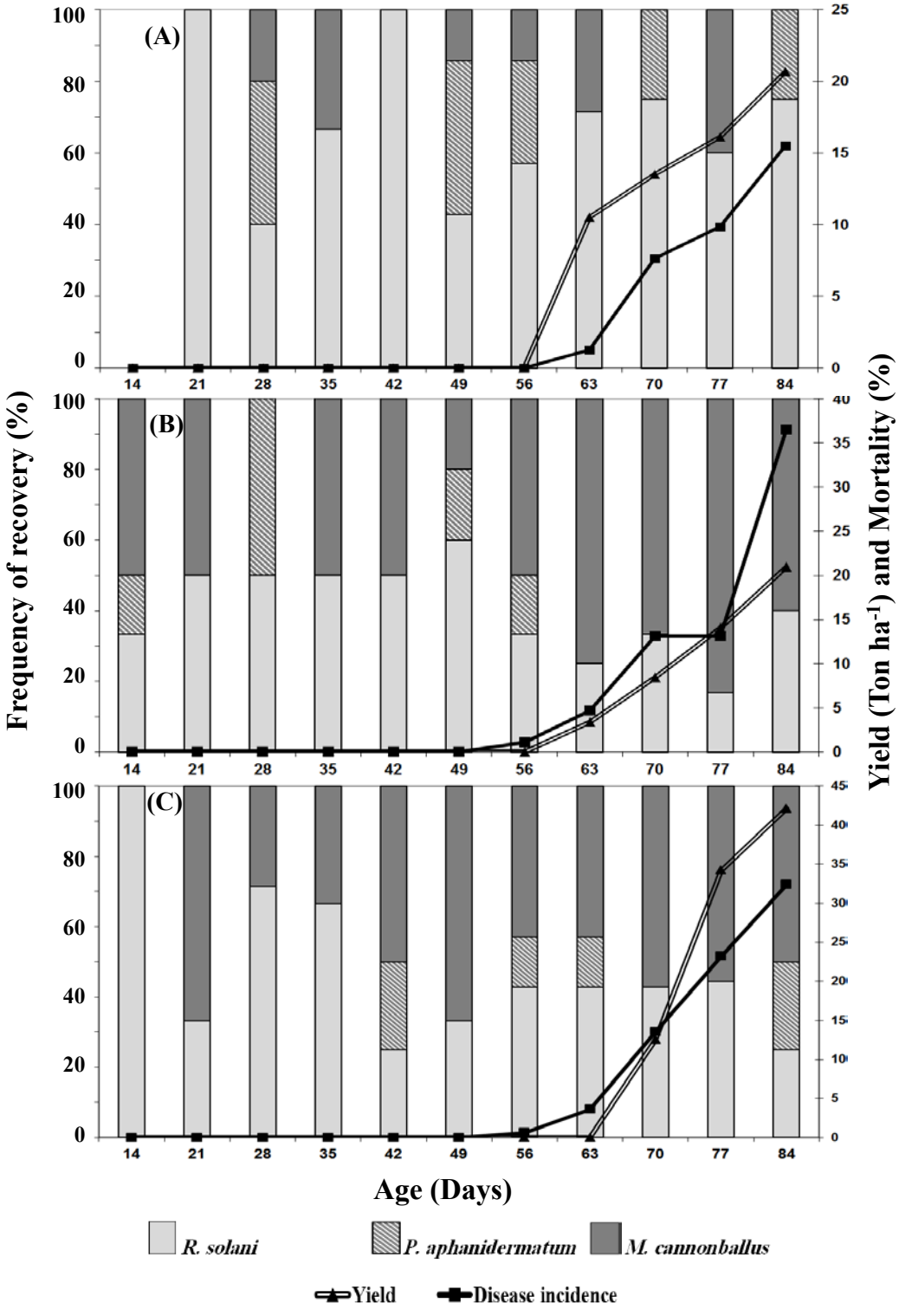

Figure 1. Development of vine decline in relation to crop age and infection with *Rhizoctonia solani*, *Pythium aphanidermatum* and *Monosporascus cannonballus* in spring 2011 (A), autumn 2011 (B) and spring 2012 (C). Frequency of recovery of fungi is presented as percentage of the total isolates recovered from five plants sampled each week.

Table 4. Field evaluation of 11 muskmelon cultivars for reaction to vine decline, growth, yield and total soluble solids (TSS) content.

Cultivar	Disease incidence (%)	Root dry weight (g)	Fruit No. (×1000 ha^{-1})	Fruit weight (ton ha^{-1})	TSS
Spring 2011[a]					
Ananas	18.9 a[b]	2.2 a	22.4 b	14.1 c	9.2 a
Ananas F1	16.1 a	2.1 a	23.8 b	16 bc	6.3 a
Caramel F1	12.2 a	1.6 ab	31.2 ab	24.1 a	7.3 a
Joyce F1	15.5 a	1.8 ab	23.4 b	20.7 ab	7.5 a
Palmira F1	18.3 a	2.1 a	27.4 ab	16.4 bc	6.3 a
Raneen	11.6 a	1.8 ab	23.8 b	24.2 a	8.9 a
Samit F1	9.7 a	1.6 ab	25.0 ab	24.5 a	8.9 a
Shahd F1	10.7 a	1.4 b	24.8 ab	21.6 ab	7.3 a
Super Sweet F1	18.5 a	2.1 a	22.2 b	18.3 abc	8.9 a
Tamara F1	7.5 a	2.1 a	22.5 b	18.2 abc	8.0 a
Punjab Sunehri	14.9 a	2.1 a	36.2 a	13.2 c	9.0 a
Autumn 2011[a]					
Ananas	23.1 ab	1.55 ab	19.6 b	18.3 b	7.5 a
Ananas F1	21.8 ab	1.13 abcd	22.9 b	19.7 b	8.7 a
Caramel F1	14.9 b	0.83 d	22 b	24 ab	10.1 a
Joyce F1	36.7 a	1.3 abcd	15.6 b	21 ab	9.9 a
Palmira F1	15.6 b	1.35 abcd	23.1 b	19.8 b	7.0 a
Raneen	10 b	0.9 cd	18 b	23.3 ab	9.2 a
Samit F1	18.6 ab	1.03 bcd	21.2 b	24.9 ab	7.7 a
Shahd F1	11.0 b	1.38 abc	22.9 b	28.4 a	9.9 a
Super Sweet F1	21.0 ab	1.65 a	21 b	22.4 ab	9.1 a
Tamara F1	22.7 ab	0.95 cd	17.9 b	24.2 ab	7.1 a
Punjab Sunehri	22.5 ab	0.93 cd	48.9 a	19.3 b	9.7 a
Spring 2012[a]					
Ananas	21.9 ab	2.2 a	29.7 b	27.5 de	9.4 bc
Ananas F1	20.5 ab	2.1 ab	27.9 b	29.4 cde	9.6 bc
Caramel F1	48.9 ab	1.9 abc	36.9 b	42.7 abc	10.3 abc
Joyce F1	32.4 ab	2.1 ab	27.2 b	42.1 abc	10.1 abc
Palmira F1	31.3 ab	2.1 abc	25.1 b	25.5 de	10.8 abc
Raneen	34.2 ab	2.0 abc	24.8 b	42.5 abc	11.2 ab
Samit F1	53.9 a	1.8 bc	31.0 b	48.9 a	7.8 c
Shahd F1	19.6 ab	1.6 c	34.5 b	46.4 ab	8.2 bc
Super Sweet F1	31.3 ab	2.1 abc	30.0 b	43.3 ab	10.0 abc
Tamara F1	17.9 b	2.0 abc	25.3 b	35.0 bcd	10.0 abc
Punjab Sunehri	32.4 ab	2.1 abc	57.2 a	19.2 e	13.1 a

[a] Average disease incidence for all cultivars was 14% in spring 2011, 19.8% in autumn 2011 and 31.3% in spring 2012.
[b] Values in each column followed by the same letter are not significantly different ($P < 0.05$; Tukey's Studentized Range test).

The 11 muskmelon cultivars exhibited variation in root dry weight, fruit number and weight and TSS. Cultivar Shahd F1 was among the cultivars which produced significantly greater yields than some others over the three seasons (Table 4). TSS varied from 6.3 to 13.1 over the three seasons, with no significant differences among the cultivars in 2011.

A negative and statistically significant correlation was found between disease incidence and fruit weight only in the spring of 2011 ($P<0.05$). No correlations were found between disease incidence and any of the other parameters studied.

Discussion

Muskmelon vine decline was widespread among the surveyed farms in Oman. Losses (0–80%) due to vine decline of muskmelon were within the range reported in previous studies (Martyn and Miller, 1996; Robinson and Decker-Walters, 1996; Zitter *et al*., 1996; Martyn, 2008). Isolation from declining muskmelons followed by pathogenicity test provided evidence that *M. cannonballus, P. aphanidermatum* and *R. solani,* were pathogenic to muskmelon. *Pythium aphanidermatum* and *R. solani* have been found associated with and pathogenic to some economically important cucurbits in Oman, such as watermelon, sweet melon, cucumber, squash and other cultivated crops (Moghal *et al*., 1993; Al-Sadi *et al*., 2011b, 2012). However, *M. cannonballus*, which has been reported previously as a pathogen of muskmelon in Israel, the USA and other countries (Pivonia *et al*., 1997; Aegerter *et al*., 2000; Martyn, 2008), is here reported for the first time as a pathogen of muskmelon in Oman. The frequency of isolation of *M. cannonballus, P. aphanidermatum* and *R. solani* (22–56%) from declining melons in Oman is broadly similar to the frequency of isolation of these pathogens from declining melons in Israel (28–95%) (Pivonia *et al*., 1997).

In this study, infection of muskmelon plants by *M. cannonballus, P. aphanidermatum* and *R. solani* started on or before d 14, but symptoms did not develop until fruit production and ripening, 60 to 70 d from sowing. Pivonia *et al*. (1997) showed that incidence of vine decline in melons increased from 12% in plants without fruits to 98% in plants with average of 2.5 fruits per plant, and this was related to increased physiological stress on fruiting plants. Findings from our pathogenicity test showed that plant mortality was generally low in 10-d-old and 20-d-old muskmelon seedlings following inoculation with *P. aphanidermatum* (mean 16.5%), *M. cannonballus* (mean 4%) and *R. solani* (mean 3%). This supports field observations of low mortality (<5%) during the initial stages of muskmelon growth compared to 36% after fruit set in some seasons. However, future studies should be undertaken to compare the response of muskmelon plants to vine decline pathogens at different host growth stages.

Variation was observed in the reaction of muskmelon cultivars to vine decline over three growing seasons. All cultivars tested were susceptible, although some (e.g. 'Shahd F1') exhibited significantly less disease than others, and produced greater yields. Growth parameters and yields were highly variable and were influenced by growing season. No correlation was found between field response to vine decline and growth or yield ($P<0.05$), which implies that these factors are independent of each other and are affected by genetic and environmental factors. The increase in the mean incidence of vine decline for all cultivars from 14% in spring 2011 to 20% in autumn 2011 and 31% in spring 2012 may be related to the effect of monoculture in the same field, which would promote increase of pathogen inoculum over time. Previous work has shown that density of pathogen inoculum is greater in soil continuously used for cucurbit cultivation (Al-Sadi *et al*., 2008c). However, further studies are required to characterize the rate of buildup of pathogen inoculum in muskmelon fields under Oman conditions. There was no evidence that increasing disease incidence was related to seasonal variation in temperature, as the average temperatures for spring and autumn were 27.9 and 28.0°C, respectively.

This study is the first to associate *M. cannonballus* with muskmelon vine decline in Oman. The occurrence of plant death during the fruiting period of muskmelons, regardless of time of infection in the field, may be related to fruiting stress imposed on plants, a hypothesis which deserves further investigation. Future research is also required to examine the influence of grafting muskmelon on rootstocks resistant to this disease.

Acknowledgements

The authors acknowledge financial support for this study through the strategic research project SR/AGR/CROP/10/01. Special thanks are given to Prof. Eileen Scott for her valuable comments on the manuscript of this paper.

Literature cited

Aegerter B.J., T.R. Gordon and R.M. Davis, 2000. Occurrence and pathogenicity of fungi associated with melon root rot and vine decline in California. *Plant Disease* 84, 224–230.

Al-Hinai A.H., A.M. Al-Sadi, S.N. Al-Bahry, A.S. Mothershaw, F.A. Al-Said, S. Al-Harthi and M.L. Deadman, 2010. Isolation and characterization of *Pseudomonas aeruginosa* with antagonistic activity against *Pythium aphanidermatum*. *Journal of Plant Pathology* 92, 655–662.

Al-Mawaali Q.S., A.M. Al-Sadi, A.J. Khan, H. Al-Hasani and M.L. Deadman, 2012. Response of cucurbit rootstocks to *Pythium aphanidermatum*. *Crop Protection* 42, 64–68.

Al-Rawahi A.K., A.A. Zouba and Y.M. Al-Maqbaly, 1998. First report of *Pythium deliense* as a causal agent of watermelon and muskmelon sudden collapse disease in Oman. *Sultan Qaboos University Journal for Scientific Research; Agricultural Sciences* 3, 126.

Al-Sa'di A.M., M.L. Deadman, F.A. Al-Said, I. Khan, M. Al-Azri, A. Drenth and E.A.B. Aitken, 2008a. First report of *Pythium splendens* associated with severe wilt of muskmelon (*Cucumis melo*) in Oman. *Plant Disease* 92, 313–313.

Al-Sa'di A.M., A. Drenth, M.L. Deadman, F.A. Al-Said, I. Khan and E.A.B. Aitken, 2008b. Association of a second phase of mortality in cucumber seedlings with a rapid rate of metalaxyl biodegradation in greenhouse soils. *Crop Protection* 27, 1110–1117.

Al-Sa'di A.M., A. Drenth, M.L. Deadman, F.A. Al-Said, I. Khan and E.A.B. Aitken, 2008c. Potential sources of *Pythium* inoculum into greenhouse soils with no previous history of cultivation. *Journal of Phytopathology,* 156**,** 502–505.

Al-Sadi A.M., R.S. Al-Masoudi, N. Al-Habsi, F.A. Al-Said, S.A. Al-Rawahy, M. Ahmed and M.L. Deadman, 2010. Effect of salinity on Pythium damping-off of cucumber and on the tolerance of *Pythium aphanidermatum*. *Plant Pathology* 59, 112–120.

Al-Sadi A.M., F.A. Al-Said, A.H. Al-Jabri, I.H. Al-Mahmooli, A.H. Al-Hinai and A.W.A.M. de Cock, 2011a. Occurrence and characterization of fungi and oomycetes transmitted via potting mixtures and organic manures. *Crop Protection* 30, 38–44.

Al-Sadi A.M., F.A. Al-Said, K.S. Al-Kiyumi, R.S. Al-Mahrouqi, I.H. Al-Mahmooli and M.L. Deadman, 2011b. Etiology and characterization of cucumber vine decline in Oman. *Crop Protection* 30, 192–197.

Al-Sadi A.M., F.A. Al-Said, S.M. Al-Quraini, S.M. Al-Kaabi, S.S. Al-Mazroui, I.H. Al-Mahmooli and M.L. Deadman, 2011c. Occurrence, characterization and management of fruit rot of immature cucumber fruits under arid greenhouse conditions. *Phytopathologia Mediterranea* 50, 421–429.

Al-Sadi A.M., 2012. Efficacy of mefenoxam is affected by a lag period between application and inactivation of *Pythium* species. *Phytopathologia Mediterranea* 51, 292–297.

Al-Sadi A.M., A.G. Al-Ghaithi, Z.M. Al-Balushi and A.H. Al-Jabri, 2012. Analysis of diversity in *Pythium aphanidermatum* populations from a single greenhouse reveals phenotypic and genotypic changes over 2006 to 2011. *Plant Disease* 96, 852–858.

Barnett H.L. and B.B. Hunter, 1998. *Illustrated Genera of Imperfect Fungi*. APS Press, Minnesota, USA, 218 pp.

Bruton B.D., J. Garcia-Jimenez, J. Armengol and T.W. Popham, 2000. Assessment of virulence of *Acremonium cucurbitacearum* and *Monosporascus cannonballus* on *Cucumis melo*. *Plant Disease* 84, 907–913.

Deadman M., H. Al-Hasani and A.M. Al-Sa'di, 2006. Solarization and biofumigation reduce *Pythium aphanidermatum* induced damping-off and enhance vegetative growth of greenhouse cucumber in Oman. *Journal of Plant Pathology* 88, 333–335.

FAO, 2012. FAOSTAT-Agriculture. http://faostat.fao.org/site/567/default.aspx#ancor.

Gubler W.D. and R.M. Davis, 1996. *Pythium* and *Phytophthora* damping-off and root rot, In: *Compendium of Cucurbit Diseases* (T.A. Zitter, D.L. Hopkins, C.E. Thomas ed.), APS Press, St. Paul, Minnesota, USA, 21–22.

Leslie J.F. and B.A. Summerell, 2006. *The Fusarium Laboratory Manual*. Blackwell Publishing, Iowa, USA, 388 pp.

Martyn R.D., 2008. Late-season vine declines of melons: pathological, cultural or both? *Phytoparasitica* 36, 309–312.

Martyn R.D. and M.E. Miller, 1996. Monosporascus root rot and vine decline. *Plant Disease* 80, 716–725.

Moghal S.M., P. Shivanathan, A. Mani, A.D. Al-Zidjali, T.S. Al-Zidjali and Y.M. Al-Raeesy, 1993. Status of Pests and Diseases in Oman: Series 1: Plant Diseases in the Batinah. Ministry of Agriculture and Fisheries, Muscat, Oman.

Pivonia S., R. Cohen, U. Kafkafi, I.S. Ben-Ze'-ev and J. Katan, 1997. Sudden wilt of melons in southern Israel: fungal agents and relationship with plant development. *Plant Disease* 81, 1264–1268.

Plaats-Niterink A.J.V.D., 1981. Monograph of the genus *Pythium*. *Studies in Mycology* 21, 1–242.

Robinson R.W. and D.S. Decker-Walters, 1996. *Cucurbits*. CAB International, UK, 226 pp.

Tsay J.G. and B.K. Tung, 1995. The occurrence of Monosporascus root rot/vine decline of muskmelon in Taiwan. *Plant Pathology Bulletin* 4, 25–29.

Zitter T.A., D.L. Hopkins and C.E. Thomas, 1996. *Compendium of Cucurbit Diseases*. APS Press, St. Paul, Minnesota, USA, 87 pp.

Accepted for publication: February 16, 2013