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Toward Integrated Management of Monosporascus Wilt of Melons in Israel

The phenomenon of melon wilting due to *Monosporascus* infection (Fig. 1) is known in many regions around the world and has been referred to as melon collapse (13,27,32,38), sudden wilt (2,6,8,26,29), root rot (17,39), vine decline (1,3,36), and root rot and vine decline (21–23,41,42). This disease is known also in the 'Arava Rift Valley of southern Israel (8,19,26,31; Fig. 2), and the major causal agent is *Monosporascus cannonballus* Pollack & Uecker (Fig. 3). This pathogen is common in hot, semiarid melon-growing areas of India (22), southern Spain (13), southwestern regions of the United States (23,24,36), Saudi Arabia (15), Central America (1), Japan (40), Taiwan (37), and Tunisia (21).

This disease in the 'Arava can be very severe, capable of destroying the entire crop (26), and will be referred to here as Monosporascus wilt. To date, disease management in the 'Arava (38) has been mainly based on methyl bromide fumigation of the soil prior to planting. Since methyl bromide use will be prohibited in the near future (33), there is an urgent need to develop alternative strategies for disease management.

Melon root rot and vine decline caused by *M. cannonballus* has been reviewed in a feature article by Martyn and Miller (22), which describes the biology, pathology, and epidemiology of the disease, as well as molecular methods for detecting variation in the pathogen population. In this article, we discuss approaches for the control of Monosporascus wilt, with an emphasis on the potential for integrated management, in view of the coming phaseout of methyl bromide. These approaches include breeding for resistance, grafting melon plants onto resistant *Cucurbita* and melon rootstocks, changes in irrigation schemes, improved soil solarization, chemical control with fungicides, and the use of other fumigants, alone or combined with soil solarization, to improve disease control.

In field trials conducted by Reuveni and Krikun in the Jordan Valley and southern 'Arava region in Israel (Fig. 2) in the early 1980s, it was shown that *Monosporascus eutypoides* (apparently synonymous with *M. cannonballus*) is the primary agent of melon collapse (19,31). Pathogenicity tests performed in 1995 and 1996 suggested that the most virulent species involved in the melon collapse syndrome in the 'Arava (Fig. 2) is *M. cannonballus*, although other pathogens might also be involved (26). *Monosporascus* appears to be adapted to hot climates. This can be inferred from the climatic conditions in the areas in which the fungus has been found and by its growth temperature optimum. Vegetative mycelial growth is extensive in the range of 25 to 35°C, and perithecia formation in vitro is optimal at 25 to 30°C (22).

In commercial fields in Israel, the melon crop can be totally destroyed by Monosporascus wilt in the autumn cropping season, whereas disease incidence and severity in a crop raised in the same plot during the following winter–spring season can be much lower (2). Differences in soil temperature between crop seasons have been suggested as a possible cause for such a phenomenon (17,28). This idea has been supported by enhanced wilting obtained following artificial heating of the soil during the winter–spring crop season (28).

Soil fumigation with methyl bromide before planting is the most common approach for controlling Monosporascus wilt of melons in Israel. Methyl bromide has lethal exposure periods as short as 2 days and can be applied at relatively low temperatures. The aeration period to eliminate volatile residues before planting is short in most soils, 3 to 10 days, allowing planting shortly after treatment (18). In fact, melon cultivation in the 'Arava region is extremely risky without methyl bromide fumigation prior to planting, due to the ubiquity of *M. cannonballus* in 'Arava soils that results in severe yield losses. The phaseout of methyl bromide in developed

Fig. 1. Late stage of wilt of melons caused by *Monosporascus cannonballus*.

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Publication no. D-2000-0229-01F

countries presents a challenge for the scientific agricultural community to develop alternatives that are both effective in pest control and environmentally acceptable. In developing management methods for Monosporascus wilt in melons, we should examine the performance of potential alternatives, including nonchemical alternatives, and integrate various approaches of disease management. Integration increases the chance of developing effective management programs by combining partially effective methods, reducing the chances of negative side effects, and providing flexibility in adapting the control programs to different agricultural situations. These also are true for all soil pests methyl bromide is used to manage.

Nonchemical Approaches to Disease Management

Breeding for resistance. The use of resistant cultivars is one of the best alternatives for reducing damage caused by plant diseases. Resistance to Monosporascus wilt in melons has only recently been included as an objective in large-scale breeding programs. This may stem from the lack of resistant germ plasm, from difficulties in assessing the resistance under field conditions, or from low commercial priority in seed companies. Breeding for resistance also may have been given a lower priority due to the availability of methyl bromide, which in most cases has provided good protection from the disease.

There are differences in the response of melon accessions to Monosporascus wilt. Ananas and Honeydew melons tested in the United States were more tolerant to the disease than U.S. cantaloupes (24,36,42). However, in experiments conducted in Israel, the Israeli cultivar Ananas Yoqne'am and the Ananas-type melon cultivar Deltex were susceptible (R. Cohen, *unpublished*). The differences in results obtained in the two locations might be due to differences in inoculum level in the soil or pathogen virulence. The tolerance of the Ananas-type melon relative to susceptible cultivars is attributed in part to its larger and more vigorous root system, which is better adapted to dry-land cropping (5). Currently, resistant melon cultivars are not commercially available. In a survey conducted in the early 1990s in the 'Arava, high tolerance was found in two melon lines, P6a, a breeding line developed from genetic material originating in Southeast Asia, and F35a, a Galia-type breeding line (2) (Table 1). Plants of these accessions either did not collapse or exhibited a significantly lower collapse rate than commercial cultivars grown in this region.

Genetic control of resistance–tolerance was investigated using crosses between resistant and susceptible genotypes identified in the survey. The results (Table 2) do not indicate the number of genes controlling tolerance to wilting, but they suggest

Fig. 2. Map of Israel with the locations in which Monosporascus wilt of melons was found and investigated. Blue dots are locations in which the disease was investigated by Reuveni and Krikun (19,31,32), Red dots are locations in the 'Arava Rift Valley, in which the disease was investigated by the authors of the present article. Monosporascus wilt of melons was found in the autumn season of 1999 in Ramat Negev (yellow dot).

Table 1. Response of melon genotypes to Monosporascus wilt in 'En Yahav (harvested in May and September) and 'En Tamar (harvested in November) 1993[w]

No.	Entry[x]	Harvest date			Maturity[y]
		May	September	November	
1	'Arava	2.5±0.5	2.7±0.2	1.0±0.4	3.0±0.0
2	Hemed	2.2±0.2	2.5±0.5	2.3±0.4	3.5±0.3
3	Maqdimon	2.7±0.5	1.5±0.3	0.5±0.3	1.5±0.3
4	Revigal	2.7±0.2	3.0±0.4	1.6±0.2	2.2±0.2
5	M 1020	NT[z]	2.7±0.2	0.8±0.5	1.7±0.2
6	F35a	0.2±0.2	2.7±0.5	0.2±0.1	0.0±0.0
7	F35d	2.7±0.5	0.0±0.7	1.6±0.4	1.2±0.2
8	F20	NT	3.2+0.2	1.6±0.6	2.7+0.2
9	GOB	0.5±0.5	0.7±0.7	0.0±0.0	4.0±0.0
10	ARZ	0.5±0.3	2.7±0.5	0.4±0.2	4.0±0.0
11	MNSI	0.7±0.5	0.5±0.3	0.0±0.0	3.2±0.2
12	FRC	20.±0.7	1.7±0.7	0.4±0.2	0.2±0.2
13	P20	0.5±0.5	3.2±0.7	0.0±0.0	0.2±0.2
14	P6a	1.0±0.4	0.5±0.5	0.8±0.3	0.0±0.0
15	D17	3.7±0.2	4.0±0.0	2.3±0.4	0.2±0.2
	Mean	1.7±0.4	2.2±0.4	2.3±0.4	

[w] Values represent wilt index, means of four replicates ± SE (2). Wilt index: 0 = no collapse; 1 = initial wilting – reversible turgor loss (overview of the whole plot); 2 = collapse of up to 50% of plants; 3 = collapse of up to 75% of plants; 4 = total collapse of all plants.

[x] Entries 1 to 4 are commercial cultivars from Hazera' Seed Co.; 5 is a breeding line of Pioneer Co., Israel; 5 to 8 are Galia-type breeding lines; 9 to 11 are entries exhibiting low wilting index in preliminary observations (GOB = Golden Beauty, Hollar Company, ARZ and MNSI = short-internode cantaloupes, FRC = Freeman's cucumber); 13 to 15 are Oriental pickling melons.

[y] Maturity index related only to experiment harvested in November at 'En Tamar. Fruit maturity index: 0 = fully ripe fruits; 1 = ripening fruit; 2 = color breaking (100% of fruits); 3 = color breaking (25% of fruits); 4 = late maturity.

[z] NT = not tested.

an additive mode of gene action (2). During the past few years, crosses have been made to introduce resistance from cultivar Black Skin, a melon from Taiwan, into a commercial Galia melon and into western shipper-type melon lines. Selections in the segregating populations were conducted in a highly *M. cannonballus*–infested field. In addition to the genetic background, other features such as fruit maturity and environmental stresses may contribute to the rate of disease progress (27,28,41) (Table 1). These can make selection of tolerant plants complicated and should be studied and taken into consideration in breeding programs. Currently, first experimental hybrids possessing resistance to the disease combined with high fruit quality are being evaluated as a basis for a large-scale breeding program (Fig. 4).

Grafting melons onto *Cucurbita* and melon rootstocks. Growing melons and watermelons grafted onto *Cucurbita* rootstocks to manage soilborne pathogens (mainly Fusarium wilt) is common in the Mediterranean Basin and Southeast Asia (20). Grafting is not used in Israel on a large scale due to the availability of methyl bromide, but this situation is changing rapidly, primarily in watermelons. Water-

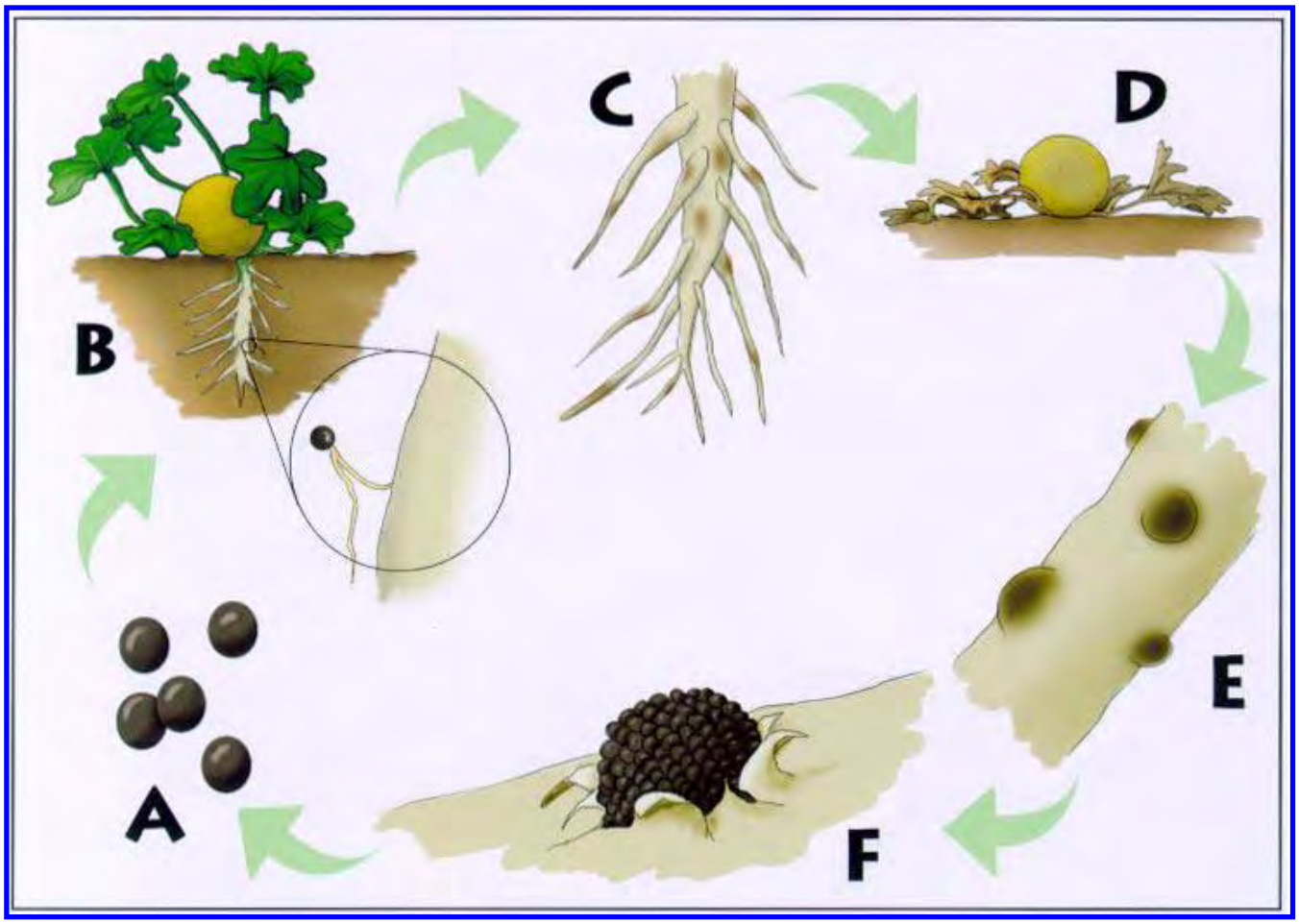

Fig. 3. Illustrated disease cycle of *Monosporascus cannonballus* in melons. (A) *M. cannonballus* ascospores without the ascus. (B) Germinating ascospore attached to melon root. (C) Lesions on melon root. (D) Wilting plant. (E) Swelling caused by perithecia formation in wilted plant root. (F) Ascospores released from perithecium. Based on references 22, 30, and 35.

melons grafted onto *Cucurbita* rootstock have good rootstock–scion compatibility, thus the use of grafted watermelons to manage many soilborne pathogens, including *Monosporascus*, is rapidly increasing. In field trials conducted in the 'Arava in the last few years, Monosporascus wilt incidence on grafted melon plants was significantly lower than on nongrafted plants (6; Fig. 5B and Table 3). Although the *Cucurbita* and bottle gourd used as rootstock are hosts of *M. cannonballus* (24,39), the slow disease development and the large root system enable the grafted plants to complete the growing season. Results of these studies indicate that grafting can be an effective method of managing melon Monosporascus wilt. However, since the rootstocks are being infected by Monosporascus, the potential for inoculum buildup in the soil by continuous usage of *Cucurbita* rootstock should be taken into consideration. Repeated usage of grafted plants should be accompanied by other management strategies to avoid this risk.

The results with grafted plants, in our experiments (6) and elsewhere (20), are variable. In addition to response to the disease, the performance of a grafted plant depends on the rootstock's compatibility with different scions, the growing season, and crop cultivation methods. In some cases, the rootstock's vigorous root system on a grafted plant is capable of absorbing water and nutrients more efficiently than the nongrafted plant and may serve as a supplier of endogenous plant hormones. Thus, rootstock performance may lead to yield increases beyond that due to disease control (4,20). On the other hand, poor rootstock–scion compatibility (Fig. 5A) may lead to yield reduction, poor fruit quality, and plant collapse (20). Preliminary observations in the 'Arava have revealed that the performance of melons grafted onto *Cucurbita* rootstocks is better when the plants are grown prostrate in the open field than trellised in greenhouses (S. Pivonia, *unpublished*). More research is needed to identify rootstock–scion combinations adapted to specific agricultural practices and seasons.

The use of *Monosporascus*-resistant melons as rootstocks is currently being investigated as a side branch of a melon-breeding program. Melons grafted onto melon rootstocks may give better rootstock–scion compatibility without yield reduction. This approach can serve as a short-term solution until high-quality resistant melon cultivars are released.

Effect of irrigation regime on wilt incidence. The response of melon plants to Monosporascus wilt incidence may be attributed in part to the size and structure of the root system. Crosby and Wolff (5) suggested that the melon cultivar Deltex (Ananas type) is more tolerant than Caravelle (western shipper) due to Deltex's more vigorous root system. The size and structure of the root system can be manipulated by the irrigation regime. In the 'Arava region, melons are drip-irrigated daily for maximum yield. This irrigation regime results in a relatively small root system that fails to provide sufficient water to diseased plants under high transpiration rates, thus contributing to enhanced wilt.

We studied the impact of irrigation regime on melon plants grown under two different regimes in an experiment in the 'Arava: traditional daily irrigation (Fig. 6A and C) and a low-level, less frequent water application (Fig. 6B and D). In the low-irrigation treatment, water supply was stopped at the three- to five-true-leaf stages. After 1 week, water supply was resumed and plants were watered every other day at a rate of 50% of daily evaporation. At the fruit-growth stage, plants in the low-level regime were irrigated daily at 50% of evaporation rate, compared with 90% supplied to plants in the daily irrigation scheme. In the daily irrigated plots, first wilt symptoms were observed 47 days after planting, and plants totally collapsed 13 days later. No marketable yield was harvested from these plots (Fig. 6C). In the less frequently irrigated plants, first wilt

Fig. 4. (A) Melon lines resistant (left) and susceptible (right) to Monosporascus wilt at harvest. (B) Early collapse at fruit netting stage of the susceptible cultivar Revigal. (C) Fruit netting stage of resistant breeding line.

symptoms were observed 60 days after planting and fruit was harvested (Fig. 6D), although 70% less fruit was harvested than in commercial melon cropping in this area treated with methyl bromide. In the daily-irrigated plots, the root system penetrated to a depth of 20 cm, whereas plant roots under the less frequent irrigation scheme penetrated the soil to depth of 40 cm (Pivonia et al., *unpublished*).

A study conducted in the 'Arava in the early 1980s (32) showed that daily irrigation closer to fruit harvest delays wilting compared with irrigation given every 3 days. The hypothesis was that daily irrigation saturates the soil and the diseased plant has enough water to resist wilting compared with the drier soil in the less frequent irrigation. However, a comparison between these two studies in the 'Arava is difficult because they were designed differently. It is clear, however, that changing the irrigation regime manipulates the size of the root system and can reduce disease incidence. Nevertheless, the risks of reduction in yield and quality compared with methyl bromide–treated plots cannot be ignored. Irrigation cannot be used as the sole managing practice for this disease, but rather as a component in a management program. There is a need to further study this issue in order to optimize the irrigation regime and combine it with other management practices to obtain disease reduction with acceptable yield.

Table 2. Monosporascus wilt incidence (%) in two genetic populations of melon (A and B)

		Wilt incidence (%)	
Genetic population[z]	**Entry**	**'En Tamar**	**'En Yahav**
A	P6a – tolerant	6±3	13±4
	D17 – susceptible	88±3	96±2
	F_1	63±4	56±6
	F_2	66±4	49±4
B	BSK – tolerant	3±2	9±2
	P202 – susceptible	82±3	90±5
	F_1	39±6	40±6
	F_2	45±3	37±3
Backcross	(F_1×BSK)	16±4	24±2
Backcross	(F_1×P202)	71±5	69±5

[z] Experiments were conducted at two locations in the 'Arava Valley in spring 1994. Values are means ± SE (2). A: P6a (tolerant), D17 (susceptible) F_1, and F_2 populations. B: BSK (tolerant), P202 (susceptible), F_1 and F_2 and backcross populations. Thirty and 60 plants were used for homogenous and segregating plant populations, respectively.

Improved soil solarization in soilless culture. Because *M. cannonballus* is a heat-tolerant fungus, traditional soil solarization, in which solar energy heats a large soil volume, is ineffective in controlling Monosporascus wilt of melons (32; Table 4). An improved soil solarization method was developed for melons grown in the greenhouse in soilless culture in which a polypropylene board was folded to create a sleeve (20 cm wide, 15 cm high) and filled with volcanic ash as a growth medium (29). The sleeves were covered with transparent polyethylene and were exposed to solarization. The efficacy of solarizing closed and open sleeves was compared. The hypothesis was that the substrate vol-

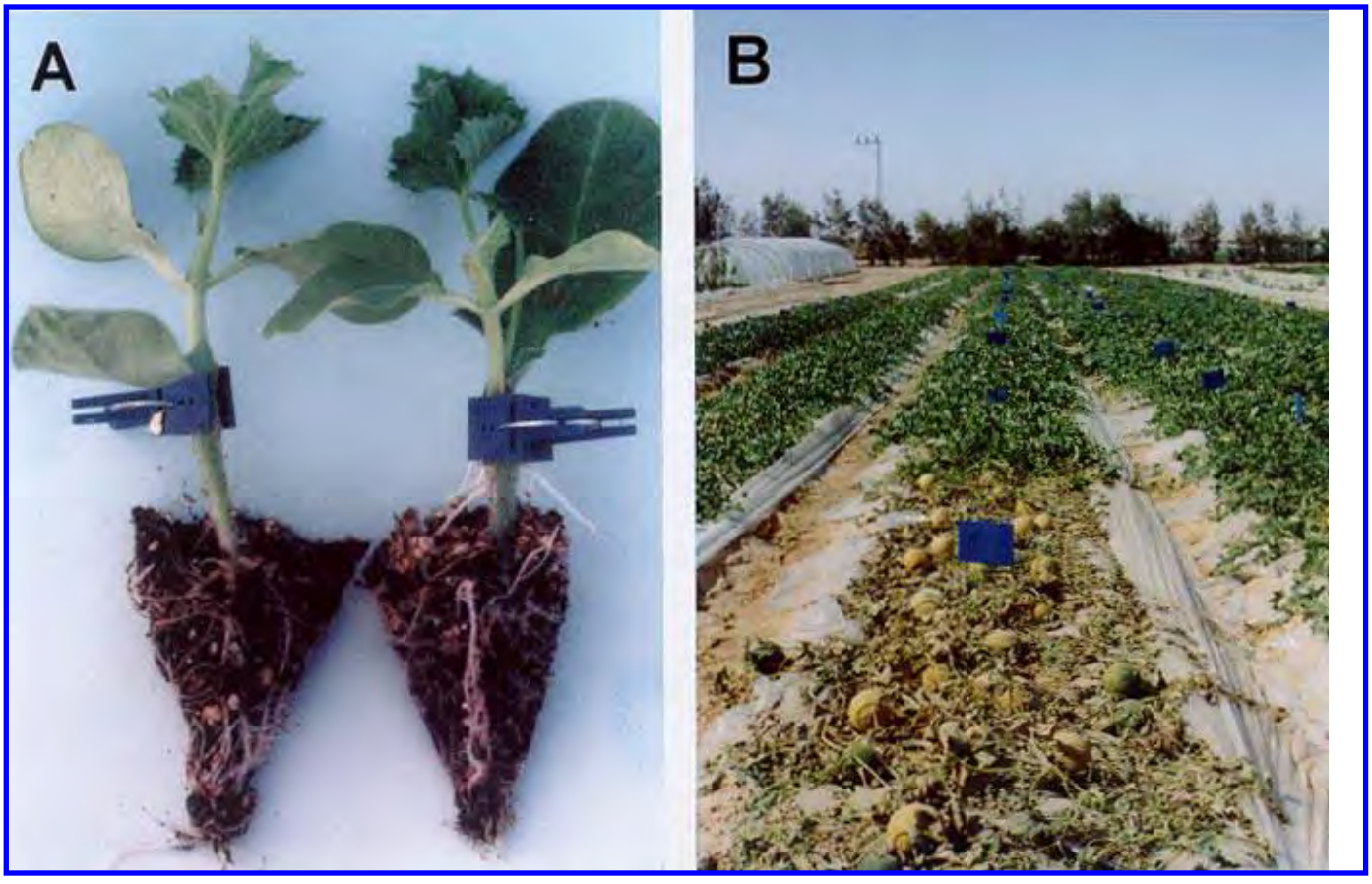

Fig. 5. (A) Melon scions grafted onto squash rootstocks. Left, good rootstock–scion compatibility, as exhibited by absence of adventitious root formation; right, poor rootstock–scion compatibility as exhibited by formation of adventitious roots. (B) Monosporascus wilt of nongrafted plants in the center foreground, compared with healthy melon plants grafted on various squash and melon rootstocks in the rest of the bed.

ume in a shallow layer would reach higher temperatures after solarization, which might be lethal to the pathogen in the open sleeve. Indeed, maximal temperatures achieved during solarization of the bedding in the closed position reached 52°C at the bottom (9 cm deep, Fig. 7A). Opening the sleeve walls and spreading the medium increased the maximal temperature to 60°C at the bottom (5 to 6 cm deep, Fig. 7B). The medium was solarized for 30 days. After termination of the solarization, the beds were rebuilt and prepared for planting. Only 7% of the plants grown in the open-solarized sleeves wilted (Fig. 7), compared with 100% in the nonsolarized, open-sleeve treatment and 62% in the solarized closed container (29). *Monosporascus* ascospores were buried in the medium prior to the treatment for testing solarization efficacy. Ascospore germination and attachment to melon seedling roots was evaluated after ascospores were exposed to a different solarization treatment using a method based on Stanghellini et al. (35). Heat treatment efficacy was also evaluated in a controlled laboratory experiment. Ascospores were exposed to different temperatures, and their germination ability was evaluated using the same method (35). Ascospores that were buried at a depth of 5 cm in the solarized open sleeves were not able to germinate. Significant reduction in germination ability was evident also with ascospores buried at a depth of 9 cm. Only five germinating ascospores were observed, compared with 23 germinating ascospores buried at the same depth in nonsolarized sleeves. The results obtained in the controlled laboratory tests revealed that exposure of *Monosporascus* ascospores to 60°C for 5 h was sufficient for total inhibition of ascospore germination (29).

Chemical Approaches

Fungicide application. Compared with fumigation, the use of fungicides in the soil is usually less expensive. In addition, fungicide chemistry and application is generally more specifically targeted and is likely to have less adverse effects on soil microbial populations and diversity. Fungicide application to crops for the management of soilborne pathogens is mainly practiced with seedling disease pathogens such as *Pythium* and *Rhizoctonia*, since the plants need only short-term protection. This approach is not used with soilborne pathogens such as *Fusarium*, *Verticillium*, and *Monosporascus*, which cause diseases in mature plants (7,34). Fungicide efficacy in soil also depends on the physical, chemical, and biological properties of both the soil and the fungicide used. Processes such as sorption, degradation, mobility, penetration into the host tissue, and translocation within the plant determine the activity of a compound (14).

We examined the efficacy of 29 fungicides against *M. cannonballus* in vitro (3). Among the fungicides tested, fluazinam and kresoxim-methyl were the most effective, and both inhibited the growth of *M. cannonballus* at concentrations of 10 µg a.i./ml. Because fluazinam also inhibited *P. aphanidermatum*, which may be involved in melon sudden wilt, and kresoxim-methyl did not inhibit this pathogen, fluazinam was chosen for field experiments (3).

Fluazinam efficacy in the field was variable (3,43; Table 5). Variation in control may result from differences in inoculum level in soil, growing conditions, temperatures prevailing during the season, and fungicide application method. Soil thin-layer chromatography and field soil analysis revealed that fluazinam mobility in soil

Table 3. Effects of methyl bromide (M.Br.) and grafting on Monosporascus wilt and melon yield, in an experiment conducted at 'En Tamar in autumn 1997[z] (6)

Treatment		Wilt incidence	Yield	Marketable fruits
Soil	Grafting	(%)	(kg/m^2)	(no./m^2)
Untreated	–	94	1.35	1.40
	+	12	2.23	1.79
M.Br. 15 g/m^2	–	8	2.66	2.47
	+	0	2.74	2.29
M.Br. 50 g/m^2	–	7	2.56	2.39
	+	0	2.63	2.44
LSD		10.3	0.76	0.18

[z] Melon (cv. 'Arava) transplants were grown in soil naturally infested with *Monosporascus cannonballus* at 'En Tamar.

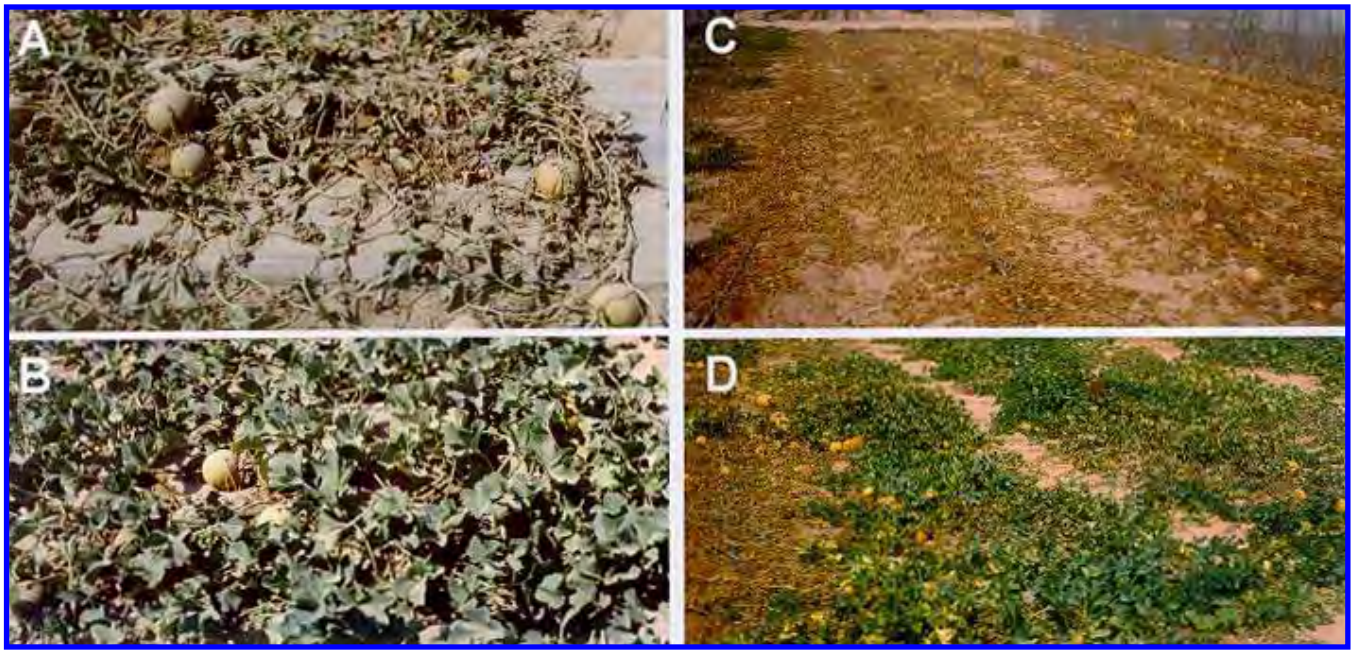

Fig. 6. Effect of irrigation regimes on wilt incidence in melons. Early and late stages of wilt with traditional daily irrigation (A and C), compared with healthy plants with less frequent irrigation (B and D). Experiments were conducted in two seasons: (A and B) in autumn 1999, and (C and D) in autumn 1998.

is limited. Although fluazinam was effective in the sandy soils of the 'Arava (3), the efficacy of this fungicide in other soils needs to be examined. More research to identify the causes of these erratic results is needed before fluazinam (or other fungicides) can be recommended for commercial use for disease suppression.

Combined Soil Disinfestation Practices

Soil fumigation alone or combined with soil solarization. Since the phaseout process was initiated for methyl bromide in 1992, approaches for reducing dosage and emission were developed, as well as alternative approaches, including the use of other fumigants and fumigants combined with soil solarization.

Methyl bromide at 50 g/m^2 effectively controls *M. cannonballus* and produces a commercially acceptable melon yield (9,22,32). Methyl bromide can also be effective at lower dosages when applied under impermeable films that minimize its escape, thereby maintaining a relatively higher methyl bromide concentration in the soil for an extended period (9,11,12). The result of using impermeable films with reduced doses is emission reduction without reduced effectiveness of pest control. Indeed, control of *M. cannonballus* using methyl bromide at 20 g/m^2 under impermeable films (Table 6) or at 15 g/m^2 when combined with solarization (Table 4) was similar to results obtained with methyl bromide at 50 g/m^2 using regular film. Mixtures of methyl bromide and chloropicrin, or 1,3-dichloropropene with chloropicrin, have been reported to reduce muskmelon collapse and increase fruit yield (22). Although methyl bromide usage will be prohibited in developed countries, the use of this fumigant at reduced dosages will be allowed for the next 15 years in the developing countries (33). Other fumigants, such as metham-sodium at 1,000 liters/ha (32), 1,3-dichloropropene (Telone), and a mixture of ethylene dibromide and chloropicrin, were not effective in controlling *M. cannonballus* when applied alone (22).

Solarization alone does not control *M. cannonballus* (32; Table 4). However, combining solarization with various fumigants at reduced dosage resulted in effective control of *M. cannonballus* and an increase in yield. The use of impermeable plastic films combined with solarization improved disease control and enabled further reduction of alternative fumigant dosages (10,12). The combination of methyl isothiocyanate–based fumigants (e.g., metham-sodium and dazomet at reduced dosages) with solarization was effective in controlling the disease, whereas each treatment alone was not effective. A mixture of 35% chloropicrin with 65% 1,3-

Table 4. Effect of fumigants combined with soil solarization on incidence of Monosporascus wilt and yield of melons[w]

Fumigant[x]	Rate (g/m^2)	Solarization	Wilt incidence[y] (%)	Yield (kg/m^2)
Methyl bromide	50	–	3.3 c[z]	3.50 a
Methyl bromide	15	+	2.5 c	3.25 ab
1,3-dichloropropene (65%) + chloropicrin (35%)	40	+	16 c	2.85 b
1,3-dichloropropene (83%) + chloropicrin (17%)	40	+	70 b	2.75 b
Dazomet	45	+	4.5 c	2.95 b
Metham-sodium	30	+	6.8 c	3.56 a
Formalin	50	+	85.5 a	1.95 c
Nontreated	–	+	90.5 a	2.45 bc
Nontreated	–	–	94.5 a	2.02 c

[w] Experiment was conducted in autumn in a field naturally infested with the pathogen.
[x] Methyl bromide was applied using the hot gas method; 1,3-dichloropropene, metham-sodium, and formalin were applied via drip-irrigation system, Dazomet was spread on the soil and rototilled. Fumigants (except for methyl bromide) were tested only in combination with solarization, since they were not effective alone in previous experiments.
[y] Percentage of diseased plants was assessed at the end of harvest.
[z] Each treatment was performed five times in a randomized block design. Values in each column not followed by same letter are significantly different according to Fisher's protected least significant difference (P = 0.05).

Table 5. Suppression of Monosporascus wilt of melons by fluazinam in four experiments conducted in the 'Arava, 1996-97 (3)

Location and season	Conditions	Fungicide application method	Disease incidence in untreated control (%)	Disease incidence in best treatment (%)
Hazeva – spring 1996	Artificially inoculated, microplots	Drenching	94	13
'En Tamar – autumn 1996	Naturally infested soil	Drenching	100	64
'En Tamar – autumn 1996	Naturally infested soil, commercial observation[z]	Via drip irrigation system	96	4
'En Tamar – autumn 1997	Naturally infested soil	Via drip irrigation system	94	11

[z] Observation (treated and untreated commercial fields with no replicates) made by company distributing fluazinam in Israel. Results published in reference 43.

Table 6. Effect of methyl bromide under two types of polyethylene tarps on incidence of Monosporascus wilt and yield of melons[w]

Treatment[x]	Plastic mulch[y]	Rate (g/m^2)	Wilt incidence (%)	Yield (kg/m^2)
Methyl bromide	LDPE	50	5 c[z]	4.7 a
Methyl bromide	LDPE	20	30 b	4.2 a
Methyl bromide	VIF	20	4 c	4.8 a
Nontreated			95 a	1.9 b

[w] Experiment was conducted in autumn in a field naturally infested with *Monosporascus cannonballus*.
[x] Methyl bromide was applied using the hot gas method, in which methyl bromide is heated by boiling water before being applied to the soil (18).
[y] LDPE = low-density polyethylene; VIF = virtually impermeable film.
[z] Each treatment was performed five times in a randomized block design. Values in each column not followed by the same letter are significantly different according to Fisher's protected least significant difference (P = 0.05).

dichloropropene was also effective when combined at low rates with solarization (9; Fig. 8). High rates of metham-sodium alone were not effective in controlling the disease (32). Formalin alone or in combination with solarization does not control the disease. A combination of appropriate fumigants (as listed in Table 4) and solarization is a feasible approach in Israel and perhaps in similar climatic regions, where melons are grown in infested soils.

Concluding Remarks

The lesson to be learned from the methyl bromide crisis is that dependence on a single method of control should be avoided, since pesticides can be banned. Methyl bromide is not an isolated instance. There appear to be promising alternative methods for the management of Monosporascus wilt of melon, as well as other diseases (33), especially when used in combination. For example, solarization, which is not effective alone in controlling a thermotolerant pathogen like *Monosporascus*, still has the potential to be a component in a disease management program, either by modifying the technology or by combining it with a suitable pesticide at reduced dosage. Similarly, partially resistant cultivars and grafting also can contribute to management programs. Grafted plants used alone or with another soil disinfestation method may satisfactorily suppress melon wilt. Any agricultural practice that improves the plant's ability to overcome the disease can be an important component in the integrated approach. Changing the irrigation schemes alone is not sufficient for disease control and can even cause yield reductions. Nevertheless, future research may lead to an irrigation regime that will contribute to disease reduction without reducing yield. Similarly, crop rotation cannot replace methyl bromide, but it should be included in management programs since it may reduce soil inoculum (25). To date, research on biological control of this disease has not been studied; therefore, this alternative should also be considered in future research.

The philosophy of integrated pest management, which aims to integrate all available methods of control in an ecologically based manner and considers economic, social, and legislative parameters, should be adopted. An appropriate combination of control methods could result in improved, wider spectrum pathogen control with long-term efficacy, concomitant with a reduction in pesticide usage (16). Combinations of disease practices may have additive or synergistic effects. This approach is especially desirable in the case of sudden wilt of melons, since additional potential pathogens may exist in the same field (26). The combined management approach is an alternative to the wide spectrum of control of methyl bromide. We now have an opportunity to introduce nonchemical approaches, or those involving reduced use of pesticides, rather than merely replacing one pesticide with another. Hopefully, the present situation will stimulate the development of breeding, grafting, crop rotation, and biological control, which have been neglected in the past due to the convenience provided by methyl bromide. To avoid failures in the era of soilborne-pathogen management without methyl bromide, certain measures need to be taken. We have to continuously monitor treated fields for early detection of any shift toward pathogens that have escaped the treatment. This is especially needed since this disease may be caused by a variety of pathogens. Information on the genetic makeup of *M. cannonballus* (22) is crucial in this regard. Methods that assess pathogen level in soil (35) and information regarding the expected disease level can become decision-making tools with respect to choosing control methods and dosage

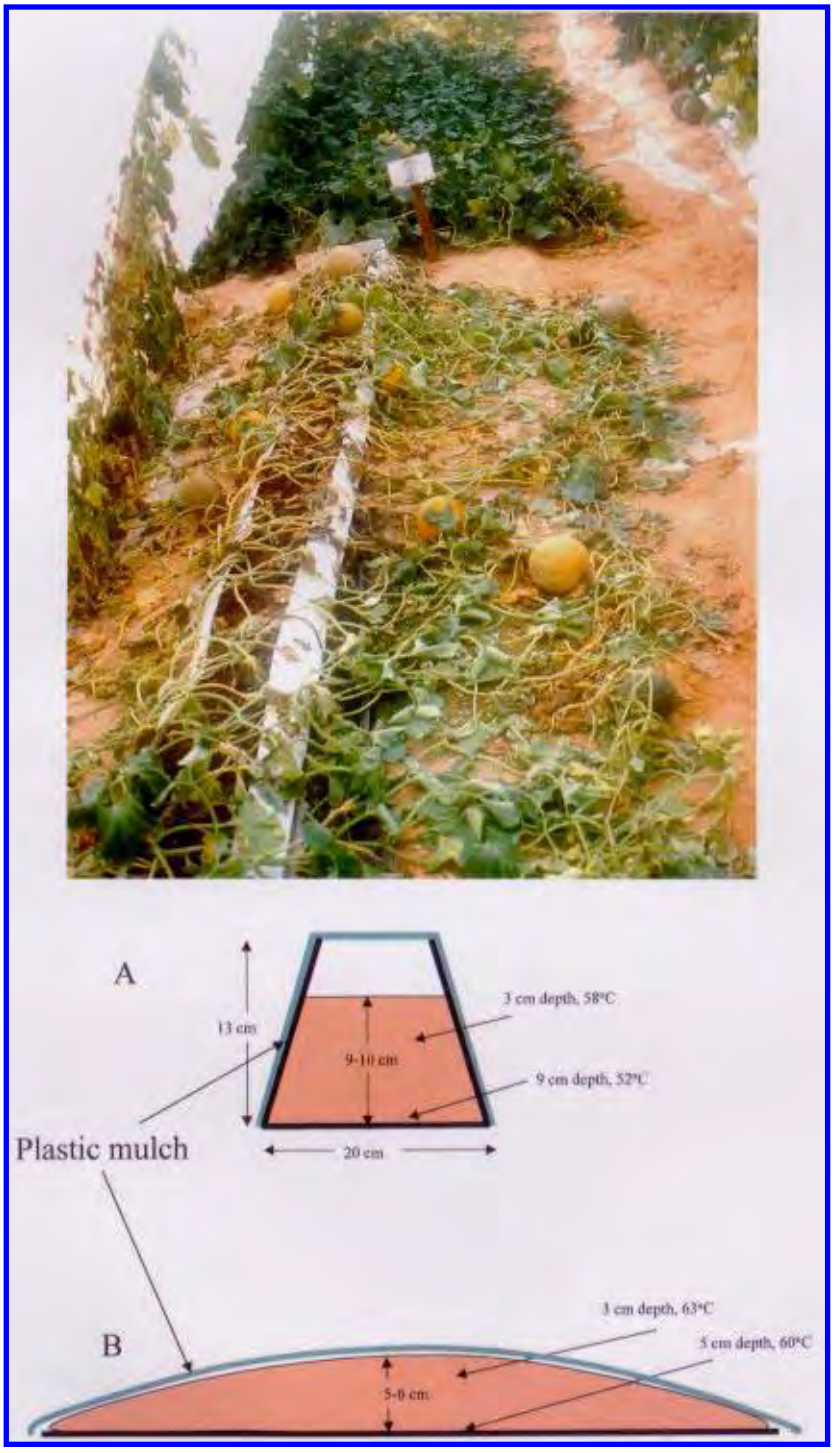

Fig. 7. Wilted melon plants (foreground) grown in sleeves that had been solarized in the closed-sleeve position, as depicted diagrammatically in (A); healthy plants (background) grown in sleeves that had been solarized in the open-sleeve position, as depicted diagrammatically in (B).

Fig. 8. Melons grown in walk-in tunnels: foreground, wilted melons grown in untreated, infested soil; background, healthy plants grown in soil treated with a combination of metham-sodium (Vapam) and soil solarization.

and frequency of application of fungicides. New findings on the biology of the pathogen, such as revealing the mechanisms of ascospore germination in the rhizosphere (35), can provide new approaches for disease management. These ideas can also be relevant, with necessary modifications, to other diseases that require alternatives to methyl bromide for management.

ACKNOWLEDGMENTS

We thank Shoshana Shriber, Newe Ya'ar Research Center, and Rachel Levita, 'Arava Research and Development, for technical support. We especially thank Rivka Offenbach and Ami Maduel of the 'Arava Research and Development for overseeing the management of the field trials, and Efrat Geva for the computerized settings of the pictures for this article. Our studies mentioned in this article were supported by grants from the Chief Scientists of the Ministry of Agriculture and the Ministry of Science Fund, by the Jewish National Fund, and by the ICA fund. Contribution from the Agricultural Research Organization, The Volcani Center, P.O. Box 6, Bet Dagan, Israel, No. 502, 2000 Series.

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