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Application Soil Solarization, on the Control of Egyptian Broomrape in Greenhouse

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Abstract

The muskmelon (*Cucumis melo*), is hardly a vegetable, but it is an important truck and garden crop. Cucumber cultivation in the Mediterranean and Midwest region is susceptible to infestation by the parasitic weed Egyptian broomrape (*Orobanche aegyptiaca*), and severe yield losses can result. The effectiveness of solarization, a soil disinfection technique that uses passive solar heating, to control the incidence of broomrape under greenhouse conditions was studied over two growing seasons. Solarization was accomplished by the application of clear polyethylene sheets to moist soil for 63 d during the hot season. The treatment increased maximum soil temperature by around 15 ºC, and at 5 cm below the soil surface, a temperature of more than 45 ºC was reached for 34 to 60 d, whereas this temperature was not reached at all in the first season and not for 20 d (second season) in unmulched soil. In solarized soil, no broomrape shoots emerged, and neither haustoria's nor underground tubercles of the parasite were found on muskmelon roots. The treatment killed about 93% of buried viable seed, and induced secondary dormancy in the remaining 7%. In nonsolarized plots, broomrape shoots were present at a high density, decreasing plant growth and fruit production. Fruit yield was 83% to 98% higher in the solarized as compared with the nonsolarized treatment. Based on these results, we suggest that soil solarization, which precludes chemical contamination and is suitable for organic farming, is an appropriate technology where the risk of Egyptian broomrape infestation is high.

Key words: broomrape (*Orobanche aegyptiaca L.*); muskmelon, Greenhouse production, muskmelon yield, solarization, soil temperature, seed viability.

INTRODUCTION

Broomrapes (*Orobanche* spp) are parasitic weeds that cause serious damage to several crops in Europe, the Mediterranean region, Central Asia, the Arabian Peninsula and some African countries (4,10,20,25,30,36,38). Most of the parasite's life cycle occurs belowground connected to the host plant and is, therefore, very difficult to control by either agronomic practices or herbicides (3,11,14,24). In addition, control is made difficult by the fact that each plant produces thousands of dust-like seeds of 0.2- to 0.3-mm-diam that are readily distributed and remain viable in the soil for many years (12). Although a broad spectrum of control methods has been attempted (cultural, physical, chemical, and biological), no significant reduction of infestation has been achieved. Hence, other control methods are needed (8,13,15,27,34, 38). The muskmelon (*Cucumis melo*), is hardly a vegetable, but it is an important truck and garden crop. There is a tendency in America to refer to muskmelons merely as "melons," but that is confusing because watermelons are also loosely called "melons." The most popular type of muskmelon in America is the small, oval, heavily netted kind commonly called a cantaloupe. All cantaloupes are muskmelons, but not all muskmelons are cantaloupes. Muskmelons have a wide range of other forms, sizes, and flesh qualities, such as the Honey Dew, Casaba, and Persian types; the large Bender, Montreal, and such odd varieties as the elongated Banana should not be called "cantaloupes." Muskmelon will not cross with watermelon, cucumber, pumpkin, or squash, but varieties within the species intercross freely. Muskmelon is so named because of the delighful odor of the ripe fruits. Musk is a Persian word for a kind of perfume; *melon is* French, from the Latin *melopepo*, meaning "apple-shaped melon" and derived from Greek words of similar meaning. Muskmelon is native to Persia (Iran) and adjacent areas on the west and the east. Persia and the trans-Caucasus are believed to be the main center of origin and development, with a secondary center including the northwest provinces of India, also Kashmir and Afghanistan. Although truly wild forms of C. melo have not been found, several related wild species have been noted in those regions. Among the *Orobanche* species, Egyptian broomrape (*Orobanche aegyptiaca L.*) is one of the most prevalent and devastating. Together with Egyptian broomrape (*Orobanche aegyptiaca* Pers.), it infests about 2.6 million ha of solanaceae crops (primarily tobacco, potato, tomato, cucumber, and eggplant) and Cucurbiaceae family (cucumber), mainly in the Mediterranean basin, North Africa, and Asia (2,4,13,18,30,34,44,43). In certain parts of Greece, Lebanon , and Jordan, Egyptian broomrape has frequently damaged tomato, tobacco, and potato fields, with 100% yield losses having been recorded (12,15,20,27,34). Other crops in the Mediterranean region commonly parasitized and severely impacted by Egyptian broomrape include sunflower, oilseed rape, muskmelon and carrot. It has become a recognized agronomic threat in western France (9) and has been recorded for the first time in Australia, Central America, and the United States (2). In Italy, branch broomrape and Egyptian broomrape

is responsible for significant yield losses in tobacco, cucumber, cabbage, and tomato (1,2,7,18,42) and has caused damage to both field and greenhouse muskmelon crops in southern Italy. Muskmelon is the main field and greenhouse vegetable crop of the coastal areas of the Mediterranean Basin and Middle East (40). In Iran, in open field, muskmelon occupies an area of 34,000 ha and produces about 4, 00 Mkg of fruit, whereas greenhouse production occurs on about 4,200 ha. Pathogen, insect, and weed management in the greenhouse relies on regular preplant soil fumigation with methyl bromide, which also controls Egyptian broomrape. However, the use of this fumigant is compromised by its destructive effect on atmospheric ozone (33). As a result, its use is scheduled to be phased out between 2005 and 2015, according to the revised Montreal Protocol. In the European Union, use of methyl bromide as a soil, commodity, and structural fumigant has been banned since January 1, 2005 (European Regulation CE 2937/2000). Therefore, there is an urgent need to identify alternative technologies for broomrape control. In southern Italy and other Mediterranean countries, an attractive alternative is soil solarization (16,21,23; 29,31,35,36,41), alone or in combination with other methods. This approach has attracted interest in many warm-climate countries because of its effectiveness, simplicity, and safety for humans, plants, and the environment (5,6). Solarization entails covering wet soil with transparent polyethylene sheets during the hot season (20,23). This serves to trap solar energy, thereby, heating the soil sufficiently to destroy soil pests. The temperature increase achieved is primarily the result of the elimination of evaporation, but is also partially because of the greenhouse effect created (28). Its effectiveness has been demonstrated in many countries around the world (22). Soil solarization has proven to be among the most effective methods of broomrape control in open field crops (14,17, 31,37). The main objective of this research was to evaluate the effectiveness of soil solarization for the control of Egyptian broomrape in heavily and naturally infested greenhouse soils in Iran and for the improvement of plant growth and fruit yield in the cucumis crop. The effect of soil solarization on germination and viability of buried Egyptian broomrape seeds was also examined.

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MATERIALS and METHODS

Site, Climate and Soil

2005 to 2006 seasons on the coastal plain south of Karaj city, in a moderately deep Calcixerollic Xerochrepts soil naturally infested with Egyptian broomrape. Before solarization, the soil characteristics were 31.4% silt, 19.3% clay, 46.5% sand, and 2.8% organic matter with pH 7.6, 1.4‰ total nitrogen (N), 136 ppm available phosphorus (P), and 520 ppm exchangeable potassium (K). The mean 25- yr maximum summer monthly temperatures are 354 ºC (June), 37.2 ºC (July), 36.1 ºC (August), and 31.2 ºC (September).

Experimental Design and Soil Solarization

In both seasons, the experiments included two treatments, solarized and nonsolarized soils, arranged in a randomized design with four replications. The plot size was 3 by 15 m. During late spring, the soil was ploughed several times to provide a uniform surface and then leveled. One day before mulching, the soil was irrigated to field capacity because solarization is more effective with moist soil (20) because of the increased thermal sensitivity of resting structures and improved heat conduction. Solarized plots were covered with 30-mm-thick transparent polyethylene film (≥ 88% total visible transmittance and 25% infrared radiation [IR] absorption) from July 10, 2005, to September 8, 2005, and from July 8, 2006, to September 11, 2006. Nonsolarized soil was similarly tilled and watered. The other weeds were handy weeded.

Soil Temperature Measurement

During solarization period, the soil temperature was recorded continuously (every 30 min) at 5 and 15 cm depths, using thermistors buried in the center of the plots (solarized and nonsolarized) and connected to a portable digital microprocessor.

Plant Material and Management Practices

Five-week-old muskmelon transplants (Nasim cultivar) were planted in October 10, 2005, and October 15, 2006, with a within-row planting distance of 0.4 m, and an interrow spacing of 1.15 m; this gave a density of 2.2 plants m2. As the plants grew, lateral shoots were removed manually, and the resulting single stem was trained to the high wire system. Plants were headed back after twelve trusses at 120 (first season) and 135 (second season) days after planting (DAP). A fertigation program, commonly used in the area for cucumis crops, was adopted (34.4 g N, 228.5 g phosphorus pentoxide [P2O5], 30.2 of potassium oxide [K2O], 25.4 magnesium oxide [MgO], and 0.5 g iron [Fe] per season per muskmelon plant). Drip irrigation was carried out when the accumulated daily evaporation reached 25 mm, 100% of maximum evapotranspiration (ETP). Pest control using standard commercial practice. Bumblebees (*Bombus terrestris* L.) were introduced into the greenhouse for improved pollination. The oldest muskmelon plant leaves were periodically removed. Harvesting was carried out from January 16, 2005, to May 6, 2005 (106 to 213 DAP), and from January 28, 2006, to May 15, 2004 (113 to 220 DAP). No additional heat, light, or carbon dioxide (CO2) was provided in the greenhouse during the crop cycle.

Seed Germination and Viability

Mature Egyptian broomrape seeds were collected in May 2004 at the same location as the experiment, and 10-mg subsamples were stored in the dark at room temperature (18 to 25 ºC). Seeds were placed in 0.15-mm by 0.15-mm fine mesh, nylon gauze bags, and on the day before the treatment initiation, bags were buried at 5 and 15 cm depth in each plot. One day after removing the polyethylene covers, all bags were recovered from the soil, the Egyptian broomrape seed was removed, and germination and viability tests were carried out. For the germination test, 250 seeds were placed in a 9-cm Petri dish on a piece of filter paper (Whatman No. 33) with 5 ml of stimulant solution and incubated in the dark at 18 6 1 ºC. The stimulant solution was prepared by dissolving 10 mg of the

synthetic germination stimulant GR242 (18; 42,43) in 10 ml of acetone and diluting 1,000-fold with a 0.3-mM buffer of 2-(*N*-morpholino) ethanesulfonic acid (MES)4, pH 6.1. Emergence was recorded under a stereomicroscope at 3-d intervals until no more germination occurred. When the germ tube was at least as long as its width (90 to 130 mm), seeds were considered to have germinated and were removed. The seed viability test was carried out by slightly modifying the procedure suggested by Khalaf (1991). Five milligram seeds were submerged for 5 min in 6% sodium hypochlorite solution to bleach the dark seed coat, then repeatedly washed in distilled water, dried in a flow of air at 40 ºC, and imbibed on Whatman paper No. 1 in 6-cm-diam Petri dishes. In each dish, 3 ml of a 1% solution of 2,3,5- triphenyltetrazolium chloride (TTC)5, prepared following International Seed Testing Association (1996) rules, was added, and the dish was incubated in the dark at 25 ºC for 72 h. Red or pink seeds were considered viable, whereas those that were not colored were considered dead (modified from (6)). Seed viability was assessed using a binocular dissecting microscope.

Data Recorded:

Egyptian Broomrape

The intensity of parasite infestation was evaluated by counting, seven times per season, between mid-November and May, the number of emerged Egyptian broomrape shoots per muskmelon plant. Egyptian broomrape shoots from four muskmelon plants for each plot were collected by hand in id-April (both seasons) and weighed. In addition, at crop arvest, all muskmelon roots of plants grown in solarized soil were collected to record the presence of Egyptian broomrape haustoria and underground tubercles.

Cucumis Crop

In both seasons, four aboveground plant samples were collected in mid-April, when the crop had reached its maximum growth rate, and fresh weight of leaves and stems was determined. Over the harvest period (from 106 to 213 DAP and from 113 to 220 DAP), the number and weight of ripe fruits harvested from 10 plants plot-1 were recorded.

Statistical Analysis

Both biological and production parameters were subjected to ANOVA where appropriate and mean separations were made following Fisher's protected LSD test. Regression analyses between Egyptian broomrape infestation and muskmelon yield (and its components) were performed.

Mean Temperature during the Crop Growth

Over the period of the crop cycle from October to early May, mean temperatures in the greenhouse maxima and minima (in ºC) for the two seasons were 33.0 and 34.0 and 24.8 and 22.4, respectively.

Results

Soil Temperature

Solarization substantially increased the soil temperature in both seasons and at both depths. The highest absolute maximum temperatures recorded at 5 cm depth in mulched soil were 54.4 and 56.2 °C in the first and second seasons, respectively, while it was 42.3 and 46.5 °C in bare soil.

The number of days when the maximum soil temperature equaled or exceeded 45, 50, 55and 60 °C at depths of 5 and 15 cm is shown in Table 1. Significantly, a temperature above 50°C at 5 cm was recorded for 31 (first season) and 51 (second season) d in solarized but for 7 (first season) and 18(second season) d in nonsolarized soil (Table 1). At 15 cm, a temperature above 50 ºC was recorded for 2 (first season) and 18 (second season) d only in solarized soil (Table 1).

Table 1. Number of days when soil temperature was ≥ 45, 50, 55, or 60 C during the solarization period at two soil depths.

Treatment		5 cm				15 cm			
		45 C	≥ 50 C	≥ 55 C	≥ 60 C	≥ 45 C	≥ 50 C	≥ 55 C	≥ 60 C
2005	Solarized soil	44	31	6	3	26	2	1	0
	Nonsolarized soil	28	7	2	0	0	0	0	0
2006	Solarized soil	51	51	39	12	47	18	0	0
	Nonsolarized soil	24	18	2	0	3	1	0	0

Egyptian Broomrape Control

In both years, Egyptian broomrape was completely controlled by soil solarization because the treatment did not allow the development and emergence of shoots, underground haustoria, or tubercles on the muskmelon roots. In contrast, in nonsolarized soil, Egyptian broomrape shoots had emerged by 45 DAP (first season) and 56 DAP (second season), and by 86 DAP (95 DAP), there were as many as 43 (52) shoots per muskmelon plant (Figure 1). At the end of the 2005 and 2006 cropping seasons, the number of Egyptian broomrape shoots per muskmelon plant peaked at 133 (± 23) and 316 (± 21) with a fresh weight of 125 g (± 11) and 173 g (± 8), respectively. Germination of Egyptian broomrape seed sown at 5 and 15 cm was zero in solarized soil, whereas it reached 83 and 81%, respectively, in nonsolarized soil.

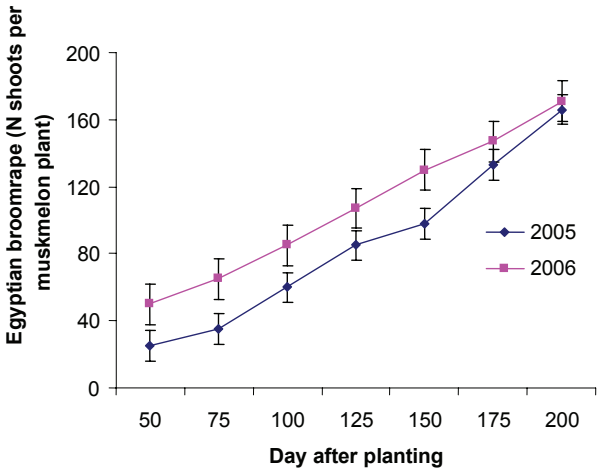


Figure 1. Number of emerged Egyptian broomrape shoots during two growing seasons in nonsolarized soil. Note the failure of shoot emergence in solarized soil. Bars represent standard errors.

The viability of buried seed at 5 and 15 cm was about 93% in nonsolarized soil but only 2% and 6% in solarized soil, respectively. No parasites other than Egyptian broomrape were found on the muskmelon roots in either the solarized or the nonsolarized soil.

Muskmelon Plant Growth and Fruit Yield

Plant growth and fruit yield were significantly higher in solarized soil than in nonsolarized soil. In mid-April, when the muskmelon plant reached its maximum size, soil solarization increased fresh leaf and stem weight per plant (Figure 2). Yield accumulation was significantly affected by soil solarization (Figure 3). In both seasons, fruit yield in solarized and nonsolarized plots was similar at the first harvest (106 DAP and 114 DAP), whereas starting with the second harvest, the yield rate of plants grown in solarized soil was significantly higher than for plants grown in nonsolarized soil (Figure 3).

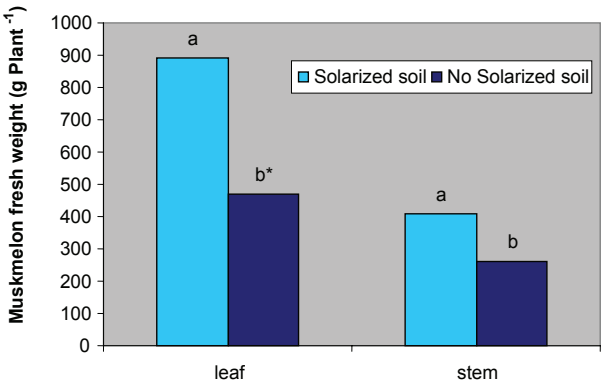


Figure 2. Effect of soil solarization on the fresh weight of cucumber plant leaves and stem in mid-April averaged mean of the two seasons. (*, significant difference at P ≤ 0.001).

At the beginning of April, the yield differences between solarized and nonsolarized plots had already reached 77% (3.9 vs. 2.2 kg plant-1, first season) and 125% (3.6 vs. 1.6 kg plant21, second season). At the end of the harvest, plants grown in solarized soil produced 5.6 (6.8) kg plan--t-1, compared with 2.4 (1.9) kg plant-1 from plants grown in nonsolarized soil, equivalent to a yield increase of 133 and 258%, respectively. Plants grown in solarized soil produced 51.5 (55.8) fruits per plant, with an average fruit weight of 71.4 g (82.6 g), whereas plants grown in nonsolarized soil produced 26.5 (21.4) fruits per plant with an average weight of 38.3 g (57.3 g), respectively. Muskmelon fruit yield (and its components) and infestation severity of Egyptian broomrape were negatively correlated (P < 0.001), as predicted.

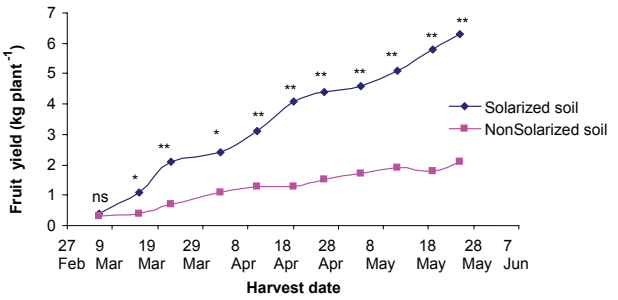


Figure 3. The effect of soil solarization on muskmelon yield under greenhouse conditions. Regression equation relating fruit yield accumulation at end harvest to infestation severity (number of emerged broomrape per muskmelon plant) was y = 0.0711x - 2781, r = 0.919**, R2 = 0.985 for the 2005 to 2006season; (*, **, and NS are significant differences at P ≤0.05, 0.01, and not significant, respective

Discussion

Under such Weather conditions [Iran (Hashtgerd)], soil solarization proved to be an excellent method for complete control of Egyptian broomrape infestation. In addition, solarization was able to consistently improve muskmelon yield under greenhouse conditions, where Egyptian broomrape is particularly destructive (16; 34; 35,39). Without solarization treatment, Egyptian broomrape consistently decreased fruit yield. As the severity of the infestation increased (over the period of mid-December to May), the growth of muskmelon plants was increasingly inhibited. The incidence of chlorosis increased, the photosynthetic rate was reduced (data not shown), and plants were visibly witted in the middle of the day, leading to a yield collapse as early as mid-spring. Fruit yield and its components were negatively and significantly correlated with the number of Egyptian broomrape shoots per muskmelon plant. Regression analysis associated 80 and 606% of the variation in muskmelon yield with the severity of the Egyptian broomrape attack for 2004 and 2006 cucumis crops, respectively. Soil solarization provided total control of Egyptian broomrape because shoot emergence from treated soil was completely inhibited, and no haustoria or underground tubercles were found on the muskmelon roots at the end of the crop cycle. The high soil temperature attained by mulching inhibited Egyptian broomrape germination killing about 95% of the buried seed and inducing secondary dormancy in the remaining 5%. This result is important because it indicates that the soil seedbank of Egyptian broomrape seed could be reduced after each solarization, and we predict that a number of consecutive solarizations will result in limiting parasite seed number in the soil to a level where normal development of the muskmelon crop is not compromised. The inhibition effects of soil solarization on broomrape seeds may be attributed to the

lethal heat effect caused by the interaction of daily fluctuating elevated temperatures and accumulations of volatiles in the soil temperatures which functions as a means of sterilizing seed of *Orobanche* or disease pathogen in the soil (19). Field trials are planned to assess the degree of viability of Egyptian broomrape seeds buried naturally in the soil after various solarization treatments because we have previously demonstrated that the exposure of crenate broomrape seeds to high temperatures led to a significant progressive reduction in germination and a linear decrease in seed viability (30,36). Soil solarization improved muskmelon plant growth and, consequently, fruit yield. The latter was 121 ± 7 and 232 ± 18% higher than in nonsolarized soil each season, respectively. Furthermore, yield levels were 598% (first season) and 84% (second season) above the average official greenhouse muskmelon yield in Iran. These remarkable increases in muskmelon yields by soil solarization are largely attributable to the absence of Egyptian broomrape infestation, but we cannot exclude additional beneficial effects generated by the solarization treatment, such as the control of soil-borne diseases, an increased release and uptake of macro and micronutrients, the release of plant growth regulators, the enhancement of mycorrhizal growth, and an increase in endogenous gibberellin supply (3; 4,6,13;29,36). Given the high correlation between yield and Egyptian broomrape infestation, as well as the absence of soil-borne pathogens, and the optimal plant nutrition maintained over the crop cycle, the additional beneficial effects provided by soil solarization are probably minor compared with the negative effects of Egyptian broomrape populations. At present, Egyptian broomrape control in greenhouses in the Iran basin and elsewhere is commonly controlled by regular preplant soil fumigation with methyl bromide; however, the use of this fumigant will be phased out by 2015 (2005 in the European Union). Therefore, Egyptian broomrape attack is currently a significant risk. Where legume cropping has been abandoned because of high *Orobanche* infection and low levels and stability of yield (8; 32), the adoption of soil solarization may be able to rescue these production areas. There are advantages to using solarization: specifically, it is a simple, nonchemical, nonhazardous method that avoids the use of any toxic materials, does not contaminate the site, and is, therefore, suitead to organic farming or other low-input agricultural systems. As global environmental quality considerations grow in importance, along with an increasing human population, evolving concepts, such as soil solarization and other uses of solar energy in agriculture, will become more important (38,39). Further research is necessary to determine the degree of Egyptian broomrape seedbank viability down the soil profile and its relationship with soil temperature reached during solarization to facilitate strategies to completely eradicate the parasite weed from the soil.

REFERENCES

1. Boari, A. and M. Vurro. 2004. Evaluation of *Fusarium* spp. and other fungi as biological control agents of broomrape (*Orobanche ramosa*). Biol. Control 30:212–219.
2. Boari, A., M. Vurro, M. A. Abouzeid, M. C. Zonno, and A. Evidente. 2003. Microbes and microbial products for biological control of parasitic weeds. Page 6 in VI International Bioherbicide Group Workshop. Canberra, Australia: International Bioherbicide Group.
3. Chen, Y. and J. Katan. 1980. Effect of solar heating of soils by transparent polyethylene mulching on their chemical properties. Soil Sci. 130: 271–277.
4. Chen, Y., Katan and J. E. DeVay, eds. Soil Solarization. Boca Raton, FL: CRC.
5. DeVay, J. E. and J. Katan. 1991. Mechanism of pathogen control in solarized soil. Pages 87–101 in J. Katan and J. E. DeVay, eds. Soil Solarization. Boca Raton, FL: CRC.
6. DeVay, J. E. and J. J. Stapleton. 1997. Soil solarization: past, present, and future. Pages 1–5 in J. J. Stapleton, J. E. DeVay, and C. L. Elmore, eds. Soil Solarization and Integrated Management of Soil-Borne Pests. Plant Production and Protection Paper 147, Rome, Italy: FAO.
7. Foti, S. 1994. Research and interventions for the quantitative and qualitative improvement of grain legumes. Subproject: broad bean, chickpea and lupin. Agric. Ricerca 155:3–8. [In Italian]
8. Gibot-Leclerc, S., F. Corbineau, G. Salle´, and D. Coˆme. 2004. Responsiveness of *Orobanche ramosa* L. seeds to GR 24 as related to temperature, oxygen availability and water potential during preconditioning and subsequent germination. J. Plant Growth Regul. 43:63–71.
9. Giovanni.M. and.L.M. Antonino. 2005. Application of soil solarization, to control branched broomrape (*Orobanche ramosa*) and improve the yield of greenhouse tomato. Weed Sci. 53:877-883
10. Goldwasser, Y., H. Eizenberg, S. Golan, and Y. Kleifeld. 2003. Control of *Orobanche crenata* and *Orobanche aegyptiaca* in parsley. Crop Prot. 22: 295–305
11. Goldwasser, Y., H. Eizenberg, J. Hershenhorn, D. Plakhine, T. Blumenfeld, H. Buxbaum, S. Golan, and Y. Kleifeld. 2001. Control of *Orobanche aegyptiaca* and O. ramosa in potato. Crop Prot. 20:403–410.
12. Gru¨nzweig, J. M., D. Haim, H. D. Rabinowitch, J. Katan, M. Wodner, and Y. Ben-Tal. 2000. Involvement of endogenous gibberellins in the regulation of increased tomato shoot growth in solarized soil. J. Plant Growth Regul. 30:233–239.
13. Haidar, M. A. and M. M. Sidahmed. 2000. Soil solarization and chicken manure for the control of *Orobanche crenata* and other weeds in Lebanon. Crop Prot. 19:169–173.
14. Haidar, M. A., W. Bibi, and M. M. Sidahmed. 2003. Response of branched broomrape (*Orobanche ramosa*) growth and development to various a. soil amendments in potato. Crop Prot. 22:291–294.
15. Hodosy, S. 1981. Biological control of broomrape, *Orobanche ramosa*, a cucumber parasite, I: occurrence and adaptability of *Fusarium* species to control broomrape in Hungary. Zoldsegtermesztesi Kutato Intezet Bulletinje 14:21–29.
16. Jacobsohn, R., A. Greenberger, J. Katan, M. Levi, and H. Alon. 1980. Control of Egyptian broomrape (*Orobanche aegyptiaca*) and other weeds by means of solar heating of the soil by polyethylene mulching. Weed Sci. 28:312–316.
17. Johnson, A. W., G. Gowdy, and A. Hassanali. 1981. The preparation of synthetic analogues of strigol. J. Chem. Soc. Perk. Trans. 6:1734– 1743.
18. Kakesh Jain and C.L. Foy, 1989. Broomrapes (*Orobanche* spp.): A potential threat to US broadleaf crops Weed Technology. A Journal of the Weed Science Society of America USA., *Orobanche* in a suitable manner. 3: 608-614.

19. Katan, J. 1981. Solar heating (solarization) of soil for control of soilborne pests. Annu. Rev. Phytopathol. 19:211–236.
20. Katan, J. 1987. Soil solarization. Pages 77–105 in I. Chet, ed. Innovative Approaches to Plant Disease Control. New York: J. Wiley.
21. Katan, J. 1991. Soil solarization present status and future prospects. Techn. Agric. 3–4:158–160.
22. Katan, J., A. Greenberger, H. Alon, and A. Grinstein. 1976. Solar heating by polyethylene mulching for the control of diseases caused by soilborne pathogens. Phytopath. 66:683–688.
23. Khalaf, K. A. 1991. Herbicidal activity of glyphosate *on Vicia faba* stimulant and germination of *Orobanche crenata* seeds in vitro. Pages 209–214 in K. Wegmann and L. J. Musselman, eds. Proceedings of the International Workshop on Progress in *Orobanche* Research. Tu¨bigen, Germany: Eberhart-Karls Universita¨t.
24. Klein, O. and J. Kroschel. 2002. Biological control of *Orobanche* spp. with *Phytomyza orobanchia*. Biocontrol 47:244–276.
25. Linke, K. H. 1987. Untersuchungen u¨ber Keimung und Jugendentwicklung von *Striga* und Orobanche. Plits 5:1–95.
26. Lolas, P. C. 1994. Herbicide for control of broomrape (*Orobanche* ramose L.) in tobacco (*Nicotiana tabacum* L.). Weed Res. 34:205–209.
27. Mahrer, Y. 1979. Prediction of soil temperature of a soil mulched with transparent polyethylene. J. Appl. Meteorol. 18:1263–1267.
28. Mauromicale, G., M. Marchese, A. Restuccia, O. Sapienza, G. Restuccia, and A.M.G. Longo. 2005. Root nodulation and nitrogen accumulation
29. and partitioning in legume crops as affected by soil solarization. Plant Soil 271:275–284.
30. Mauromicale, G., G. Restuccia, and M. Marchese. 2000. Germination response and viability of *Orobanche crenata* Forsk. seeds subjected to temperature treatment. Aust. J. Agric. Res. 51:579–585.
31. Mauromicale, G., G. Restuccia, and M. Marchese. 2001. Soil solarization, a nonchemical technique for controlling *Orobanche crenata* and improving yield of faba bean. Agronomie 21:757–765.
32. Mesa-Garcia, J. and L. Garcia-Torres. 1986. Effect of planting date on parasitism of broadbean (Vicia faba L.) by crenate broomrape (*Orobanche* crenata). Weed Sci. 34:544–550.
33. Noling, J. W. and J. O. Becker. 1994. The challenge of research and extension to define and implement alternatives to methyl bromide. J. Nematol. 26:573–586.
34. Qasem, J. R. 1998. Chemical control of Egyptian broomrape (*Orobanche ramosa*) in glasshouse grown tomato. Crop Prot. 17:625–630.
35. Qasem, J. R. and M. A. Kasrawi. 1995. Variation of resistance to broomrape (*Orobanche ramosa*) in tomatoes. Euphytica 81:109–114.
36. Sahile, G., G. Abebe and A. M. Al-Tawaha. 2005. Effect of soil solarization on *Orobanche* soil seed bank and tomato yield in Central Rift Valley of Ethiopia. World J. of Agric Sci. 1 (2): 143-147.
37. Sauerborn, J., K. H. Linke, M. C. Saxena, andW. Koch. 1989. Solarization; a physical control method for weeds and parasitic plants (*Orobanche* spp.) in Mediterranean agriculture. Weed Res. 29:391–397.
38. Stapleton, J. J. 2000. Soil solarization in various agricultural production systems. Crop Prot. 19:837–841.
39. Stapleton, J. J. and J. E. DeVay. 1986. Soil solarization a non chemical approach for management of plant pathogens and pests. Crop Prot. 5:190–198.
40. Tognoni, F. and G. Serra. 2003. Trends in Process Technologies and Products. Acta Hortic. 614:65–75.
41. Zehhar, N., M. Ingouff, D. Bouya, and A. Fer. 2002. Possible involvement of gibberellins and ethylene in *Orobanche ramosa* germination. Weed Res. 42:464–469.
42. Zonno, M. C., P. Montemurro, and M. Vurro. 2000. *Orobanche ramosa*, a parasitic weed spreading in Southern Italy. Inf. Fitopat. 50:13–21. [In Italian]
43. Zwanenburg, B., G. L. Mhehe, G. K. Lam, F. J. Dommerholt, and M. A Kishimba. 1986. The search for new germination stimulants of *Striga* species. Pages 35–41 in S. J. Ter Borg, ed. Proceedings of a Workshop on Biology and Control of Orobanche. Wageningen, The Netherlands: LH/VPO