RECENT APPROACHES FOR CONTROL OF PARASITIC WEEDS

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Abstract

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Broomrape (*Orobanche* spp.) and witchweed (*Striga* spp.) are devastating root parasites of many agricultural crops and cause severe yield losses. Conventional weed control methods, such as cultivation and the use of selective chemicals, are largely ineffective due to the close ecological and physiological relationship between host and parasite. A search for genetic resistance to broomrape, *O. aegyptiaca* in tomato has not been very encouraging. Although herbicides such as 2, 4 - D have been used against witchweed, the only effective (but expensive) means of broomrape control has been soil sterilization, by either chemical fumigation or solarization. Two recent approaches show considerable promise for controlling these parasitic weeds. Ethylene has proved very effective in stimulating suicidal germination of witchweed seeds but had been far less effective on broomrape seeds. Strigol and its synthetic analogues, however, have been observed to enhance germination of broomrape seeds in the absence of host plant exudates. Glyphosate herbicide selectively controls / suppresses broomrape in crop such as broadbean. 14 C-glyphosate is translocated from host leaves to broomrape shoots where it accumulates in concentrations greater than in any part of the host plant, including the apical meristem. An integrated approach using the seed germination stimulants and translocated herbicides such as 2, 4-D in the case of witchweed and glyphosate in the case of broomrape may prove most useful in controlling these parasitic weeds. Adequate water and nutrient supply to host plants may also reduce parasitization by broomrape and thus prevent yield loss.

Additional key words: broomrape, witchweed, methods of control

Introduction

Broomrapes (*Orobanche* spp.) and witchweeds (*Striga* spp.) are devastating root parasites of many economically important crop plants. Broomrapes belong to the family Orobanchaceae which is characterized by plants having no chlorophyll (37).

Witchweeds, on the other hand, belong to the family Scrophulariaceae which consists of plants having chlorophyll. Both parasitic weed genera have a broad host range. Broomrapes are most damaging to members of the Solanaceae, Leguminosae, Asteraceae and Brassicaceae,whereas witchweeds are most damaging to plants belonging primarily to the Gramineae family. Both parasitic weed groups are obligate heterotrophs (31), however, and resemble each other in many aspects of their life cycle.

Both broomrapes and witchweeds are annuals and reproduce by means of seeds which are usually dormant and do not germinate readily (31). In order to break the dormancy, the seeds require a period of preconditioning under suitable moisture and temperature conditions. The preconditioned seeds then germinate most successfully in the presence of root exudates from host (8) and some non-host plants (19). Seeds stimulated to germinate give out a radicle that penetrates the host roots in the vicinity of the parasite seeds (within 2 to 3 mm) and establishes a vascular connection with the host to derive water and nutrients essential for its growth (26). Following the successful establishment of the parasite seedlings on host roots, the subterranean parts of the parasite produce a shoot that elongates rapidly and emerges above the soil surface. The above-ground portion of the shoot bears the flowers that produce numerous seeds. It has been estimated that about four crenate broomrape (*O. crenata* Forsk. #[2]ORACR) plants parasitizing a broad bean (*Vicia faba* L.) plant decrease the seed yield of broad bean by one-half (30).

Several methods of control have been tried against these parasitic weeds. Although herbicides such as 2, 4-D [(2, 4-dichlorophenoxy) acetic acid], paraquat (1,1'-dimethyl-4,4'-bipyridinium ion) and oxyfluorfen [2 - chloro - 1 - (3 - ethoxy - 4 - nitrophenoxy) - 4 - (trifluoromethyl) benzene] have been used against witchweed [*Striga asiatica* (L.) Ktze.# STRLU] with some success (15, 29, 40), the only truly effective means of control against the various broomrapes now seems to be soil sterilization... either by chemical fumigation, e.g., with methyl bromide (42, 43), or by solar heating (20). Soil sterilization is very expensive, however, and it is not usually adopted on a large scale. There is a serious need, therefore, to develop other means of parasitic weed control that are both effective and economical.

Two new approaches are being tested to control broomrapes and witchweeds with the main objectives of (a) reducing the seed populations of these parasitic weeds in the soil and (b) preventing the production of new seeds. These approaches include the stimulation of seed germination of the parasitic weeds, and their control by chemical means after the parasites have established themselves on host plants. This paper deals with a discussion of progress in the development of these two approaches as related to broomrape control.

Reduction of Broomrape Seed Populations in the Soil

Broomrapes produce numerous seeds that can remain viable in the soil for more than 10 years (26, 33). Parasite seeds in the dormant state are quite resistant to most control measures except soil sterilization by fumigation or solar heating. Once broomrape seeds have germinated, they require host plants to establish themselves and complete their subsequent development. Thus, it has been recognized that broomrape seeds are most vulnerable to destruction immediately after germination but prior to their establishment on host roots. If broomrape seeds are induced to germinate in the absence of host plants, the young seedlings are unable to support themselves andsoondie of starvation. The stimulation of parasite seed germination in the absence of host plants has been termed «suicidal germination» (14) and this concept was first tested on witchweed by usingethylene gas as the seed germination stimulant (13).

The observation that broomrape seeds can germinate not only in the vicinity of roots of host plants, but also in the vicinity of some non-host plants led to the use of these non-host plants as trap crops to induce suicidal germination of seeds of various species of broomrape (6, 7). The results of field experiments applying this method showed varying degrees of success, however, mainly due to the vast distribution of broomrape seeds throughout the tilled layer of soil (3, 11).

The failure of trap crops in reducing, consistently, the broomrape seed populations in the soil led to the testing of chemical stimulants for inducing suicidal germination of parasite seeds. Ethylene gas, which has proven very effective in reducing suicidal germination of witchweed seeds, has been mush less effective in inducing suicidal germination of crenate broomrape seeds (12). Strigol, a chemical stimulant isolated from the roots of cotton (*Gossypium hirustum* L.), however, was found to be very effective in stimulating germination of both witchweed and broomrape seeds (10). Several analogues of strigol were subsequently synthesized and tested for their effect on parasite seed germination (25, 32, 34).

Two analogues of strigol, GR 7 and GR 24, have proven particularly effective in stimulating broomrape seed germination under laboratory conditions (Figure 1). In a preliminary experiment, GR 24 was found to be more effective than GR 7 in stimulating seed germination in three broomrape species (Table 1). In general, both strigol analogues appeared to be more effective in stimulating seed germination in hemp broomrape (*O. ramosa*) than Egyptian broomrape *(O. aegyptiaca)* or crenate broomrape *(O. crenata)* (22). For unknown reasons, nodding broomrape *(O. cernua)* seeds failed to germinate in these experiments.

Incorporation of GR 7 and GR 24 into the soil under greenhouse conditions has also proven effective in stimulating hemp broomrape seed germination and thus reducing infection of tomato (*Lycopersicon esculentum* Mill.) plants transplanted in broomrape-infested soil four to six weeks after incorporation of the strigol analogues (34, 35). The efficacy of these strigol analogues in the field remains to be tested, however, probably because of the continuing limited availability of these specially synthesized chemicals for large-scale experiments.

Chemical Control of Broomrape After Attachment to Host Roots

Chemical control of broomrape after attachment to host roots may be aimed at attacking the parasite directly or indirectly before it emerges above the soil surface or by treating the shoots of the parasite after they have emerged from the soil. Chemicals used to control broomrape before emergence may either be applied to the soil for a direct or to host plants for an indirect effect on the parasite. In the latter case, herbicides capable of translocation within the plant are applied to the host plant at rates that are relatively safe for the host plant itself, but are deleterious to the parasite.

Table 1. Effect of strigol analogues (growth regulators), GR 7 and GR 24, on the germination of four species of broomrape.

Treatment	Conc (ppm)	*O. aegyptiaca*	*O. ramosa*	*O. crenata*	*O. cernua*
		(% germination)			
Conrol		8.0	6.6	0.0	0.0
GR 7	0.10	17.7	19.8	1.0	0.0
GR 7	1.00	21.3	29.6	4.6	0.0
GR 7	10.00	22.0	21.9	17.1	0.0
GR 24	0.01	10.8	31.2	0.7	0.0
GR 24	0.10	20.5	32.8	6.0	0.0
GR 24	1.00	21.0	25.3	16.4	0.0
SEM		1.5	3.3	1.4	

Several soil applied herbicides have been tested against the subterranean development of broomrape on host plants with variable results (24, 27, 28, 36). Some interesting results were obtained, however, with foliarly applied herbicides such as 2, 4-D. When applied to the leaves of broad bean plants parasitized by *O. crenata*, ^{14}C-2, 4-D was observed to translocate from the host foliage to the roots and into the attached parasite. The developing tubercle of *O. crenata* was found to contain the herbicide in a concentration 14 times greater than in the host roots five days after treatment (41). Due to the high susceptibility of most broadleaf crops to 2, 4-D, however, the use of this herbicide for broomrape control is generally not acceptable. The fact that 2, 4-D was translocated and accumulated in the parasite in concentrations much higher than in the host, however, suggested that if a herbicide could be found that was no more toxic to the

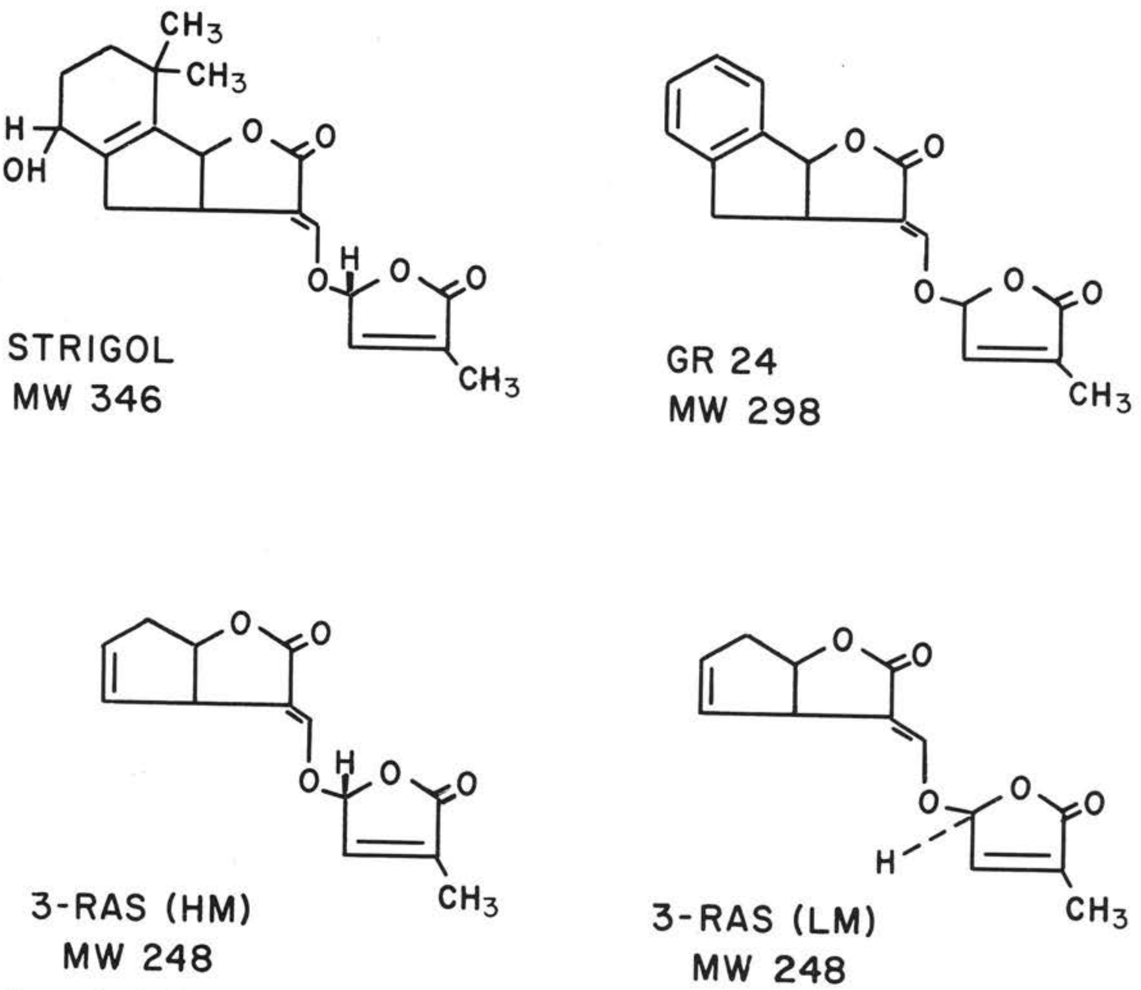

Figure 1. Structures and molecular weights of strigol, GR 24, and high melting point (HM) and low melting point (LM) isomers of a 3- ring analogue of strigol (3-RAS). GR 7 is a mixture of the two 3- RAS isomers (5).

host than to the parasite, it could be used selectively to control broomrape in crops.

Glyphosate [N-(Phosphonomethyl) glycine] is a nonselective, postemergence herbicide that is readily translocated from the point of application on the leaves to all parts of the plant. Due to its nonselective nature, glyphosate is generally applied in noncropped areas or prior to planting or after harvesting in croplands for broad spectrum weed control. This herbicide has been found to be very effective against broomrape. Very interestingly, when applied to crop plants such as broad bean at very low rates (60 to 120 g/ha), glyphosate has been observed to suppress and/or control the attached parasite without adversely affecting the host plants.

The effectiveness of glyphosates as a foliar application for *O. crenata* control in broad bean was first reported by Kasasian (27). The rate of 200 g/ha provided complete control of the parasite and sufficient safety margin, indicating the relative tolerance of broad bean to the herbicide. Similar results were obtained with *O. aegyptiaca* control in tobacco (*Nicotiana tabacum* L.) (27). Several researchers have since confirmed that glyphosate could be used selectively to control broomrape in crops such as broad bean and tobacco (20, 38, 39).

In order to understand the nature of selective control of broomrape in crops by glyphosate, the translocation and metabolism behavior of glyphosate was evaluated in two varieties of tomato plants infected with *O. aegyptiaca*. The two varieties of tomato were «Rutgers» (a commercial variety susceptible to broomrape) and «PUZ 11» (a Russian variety reported to be resitant to broomrape) (4). Surprisingly, «PUZ 11» tomato plants were as extensively infected with *O. aegyptiaca* (Figure 2) as «Rutgers» tomato plants. Autoradiographs of broomrape-infected «Rutgers» and «PUZ 11» tomato plants showed that the radiolabel from ^{14}C-glyphosate applied on tomato leaves was translocated to all parts of the host plant and particularly to broomrape, where it appeared to accumulate in the shoot meristem within three days of treatment (Figure 3). Quantitative estimation of the radiolabel by liquid scintillation spectrometry in various parts of the host plants and in broomrape shoots (on the basis of total radioactivity per gram dry weight of broomrape shoot) showed that less than half of the radioactivity applied on tomato plants moved out of the treated leaves. Radioactivity translocated from the treated tomato leaves accumulated in broomrape shoots in much greater amounts than in the apical meristem of the host. Accumulation of radioactivity in broomrape shoots increased with the time of treatment on the host leaves from three to seven days (Tables 2 and 3) (23). It has already been observed that ^{14}C-photoassimilates

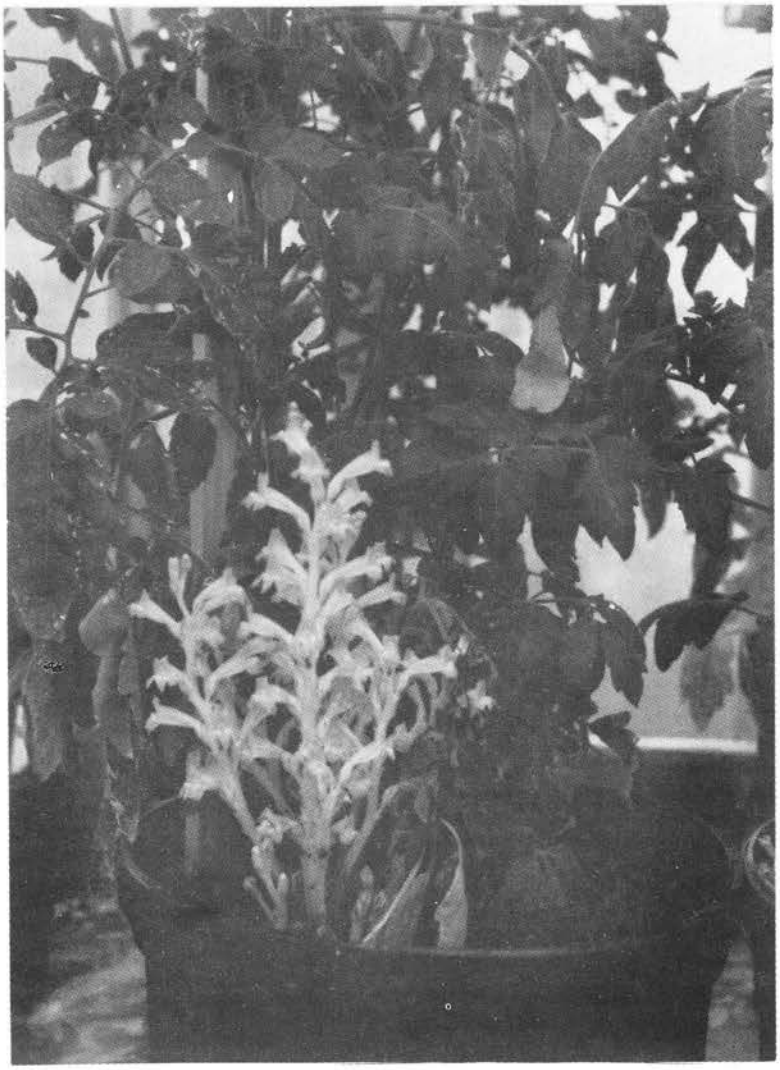

Figure 2. *O. aegyptiaca* on a «PUZ 11» tomato plant.

from tomato plants are readily translocated to the attached *O. ramosa* plants (37). Our results show that ^{14}C-glyphosate behaves in a manner similar to that of photoassimilates in a host-broomrape (tomato- *O. aegyptiaca*) system and that broomrape acts as a strong «sink» and competes directly with the apical meristem of the host for glyphosate and most probably photoassimilates. ^{14}C-glyphosate did not appear to be metabolized in either the host or the broomrape tissue (Figure 4) (23).

Although glyphosate appears to accumulate in broomrape in concentrations higher than in the apical meristem of the host plants, tomato plants treated with the low rates (50 g/ha followed by 100 g/ha) of the herbicide showed injury symptoms. Hence, the limiting factor to glyphosate deployment as a broomrape herbicide in tomato as well as in some other crops such as pea (*Pisum sativum* L.) and carrot (*Daucus carota* L.) is the narrow margin of selectivity of these crops to glyphosate (20). Subsquently, a new approach of controlling broomrape in these crops was suggested by Foy and Jacobsohn (16). According to these researchers, if some tolerance to both glyphosate and broomrape could be found in crops such as tomato, an integrated approach where genetic tolerance to the herbicide and the parasite can be combined, might be used selectively to control broomrape in crops. The presence of sufficient tolerance to either glyphosate or broomrape alone in existing tomato varieties is thought to be a remote possibility.

Table 2. Translocation of ^{14}C-glyphosate in «Rutgers» tomato plants infected with *O. aegyptiaca*.

	After 3 days		After 7 days	
Plant part	Total[a] DPM×10^3	% of total ^{14}C applied	Total[a] DPM×10^3	% of total ^{14}C applied
Treated leaves	261.0	47.5	311.0	56.6
Apical meristem	3.3	0.6	1.8	0.3
Stem + untreated leaves	6.6	1.2	2.3	0.4
Roots	7.6	1.4	8.8	1.6
Broomrape shoots	13.7	2.5	8.4	1.5
	(96.8)[b]		(101.7)[b]	

(a) Total DPM are means of two plants.

(b) Numbers in parenthesis are DPM/g broomrape shoot.

Table 3. Translocation of ^{14}C-glyphosate in «PUZ 11» tomato plants infected with *O. aegyptiaca.*

Plant part	After 3 days		After 7 days	
	Total[a] DPM × 10^3	% of total ^{14}C applied	Total[a] DPM×10^3	% of total ^{14}C applied
Treated leaves	285.3	51.9	274.2	49.9
Apical meristem	0.5	0.1	31.0	5.6
Stem+untreated leaves	5.3	1.0	55.6	10.1
Roots	8.5	1.5	12.4	2.3
Broomrape shoots	5.0	0.9	46.0	8.4
	(32.7)[b]		(51.7)[b]	

(a) Total DPM are means of two plants.

(b) Numbers in parenthesis are DPM / g broomrape shoot.

In order to test this hypothesis, a major screening program was conducted to determine which (if any) tomato lines had practical levels of tolerance to glyphosate and / or broomrape (16). Out of the 1522 tomato lines screened in the greenhouse to evaluate their tolerance to glyphosate at 37.2g / ha applied in a spray volume equivalent to 250 1 / ha, about 40 tomato lines showed fresh weights of treated plants not significantly different from those of untreated plants. All tomato varieties, however, showed injury to varying degrees from glyphosate. Repeat screening of selected tomato varieties in the greenhouse and field indicated that some tomato lines may have promise for glyphosate tolerance and deserve attention in future screening programs.

Recently, a glyphosate-tolerant gene was discovered in a genetically modified strain of a bacterium, *Salmonella typhimurium (9).* This glyphosate-tolerant gene was introduced by genetic engineering techniques into tobacco, tomato and some other crops (18). Such genetically engineered crop plants are expected to become commercially available in the early.1990's (Sun, 1986). With the availability of glyphosatetolerant crops, the use of glyphosate for broomrape control in crops such as tomato and tobacco may become a common practice.

Reduction in Broomrape Parasitism by Soil Fertilization

The nutrient status of the soil can affect the ability of broomrape to parasitize host plants. Farmers in Jordan claim that addition of chick manure to the soil reduces broomrape infestation in their fields (1). High levels of nitrogen have been observed to reduce *O. ramosa* infestations in tobacco and tomato. High nitrogen levels, however, had some adverse effects on tomato yield (2, 27). Application of potassium and phosphorus along with nitrogen overcame the drastic effects of nitrogen applications alone on tomato yields and drastically reduced broomrape infestations on crop plants (1).

In addition to soil nutrient status, soil type may also affect parasitism of crop plants by broomrape. In an experiment conducted in the greenhouse, three types of potting media were tested for their effects on broomrape parasitism of two tomato varieties. The potting media used were (A) clay loam (33.3%), sand (33.3%), and Weblite[3] (33.3%); (B) clay loam (45%), sand (45%), and peat moss (10%); and (C) vermiculite (40%), Weblite (40%), and peat moss (20%). No fertilizer was added to potting medium (A) or (B). Fertilizers, Osmocote (14 - 14 - 14) and (4 - 9 - 3) at 2.6 kg / m^3 each and lime at 1.3 kg / m^3 were added to potting medium (C). Tomato varieties tested were «Rutgers» and «PUZ 11». The results of this experiment showed that the growth of both varieties of tomato plants was much more vigorous in potting medium (C) than in potting medium (A) or (B)(Table 4). Both varieties were equally susceptible to *O. aegyptiaca.* The number of broomrape infections on tomato plants, however, were negatively correlated with the growth of tomato plants in the three potting media (Table 5). Thus, the higher nutrient status and water holding capacity of potting medium (C) than those of potting medium (A) or (B) may have been responsible for the vigorous growth of tomato plants and low infection rate by broomrape (17). Further experiments, especially under controlled environmental conditions, are required to establish the effect of soil type and nutrient status of the soil.

Conclusions

Broomrapes and witchweeds cause severe losses in yield of many economically important crops in many parts of the world. The main objectives in a control program for parasitic weeds include reduction of existing seed populations in the soil and prevention of new seed production by the parasite. An eradication program developed for witchweed control in the United States is based upon inducing suicidal germination of witchweed seeds by ethylene and the control of emerged parasite plants by certain herbicides before the parasite is able to produce seeds. Ethylene gas is much less effective in inducing suicidal germination of broomrape seeds than of witchweed seeds. Certain analogues of strigol, however, have shown considerable promise for inducing suicidal germination in both broomrape and witchweed seeds. Glyhosate has been observed to control broomrape selectively in broad bean in several field trials. The margin of selectivity of this herbicide in some other crops such as tomato, pea and carrot, however, is much lower than in broad bean. Screening of numerous tomato lines to low rates of glyphosate has indicated that practical levels of glyphosate tolerance may exist in some tomato lines. A breeding program incorporating glyphosate tolerance into the commercial varieties or the commercial availability of genetically engineered glyphosate-tolerant crops may help to selectively control not only broomrape but many other weeds by glyphosate in crops such as tomato. Integration of adequate soil fertilization may further help to reduce parasitization and thus prevent yield loss in crops due to this noxious parasitic weed.

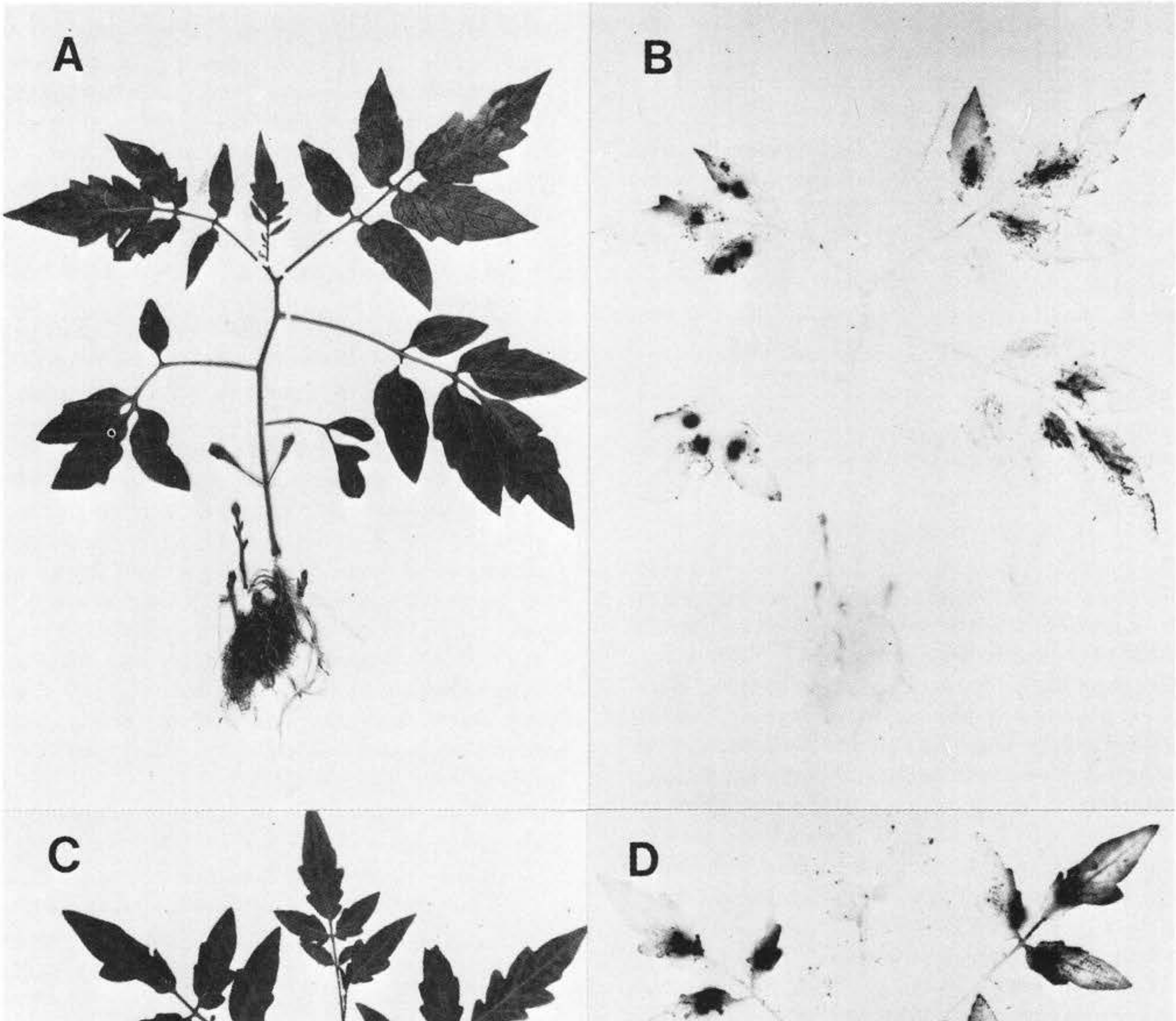

Figure 3. Translocation of ^{14}C-glyphosate in tomato plants infected with *O. aegyptiaca* three days after treatment. (A) and (B) are dry mount and autoradiogram of «Rutgers» tomato plant; (C) and (D) are dry mount and autoradiogram of «PUZ 11» tomato plant, respectively.

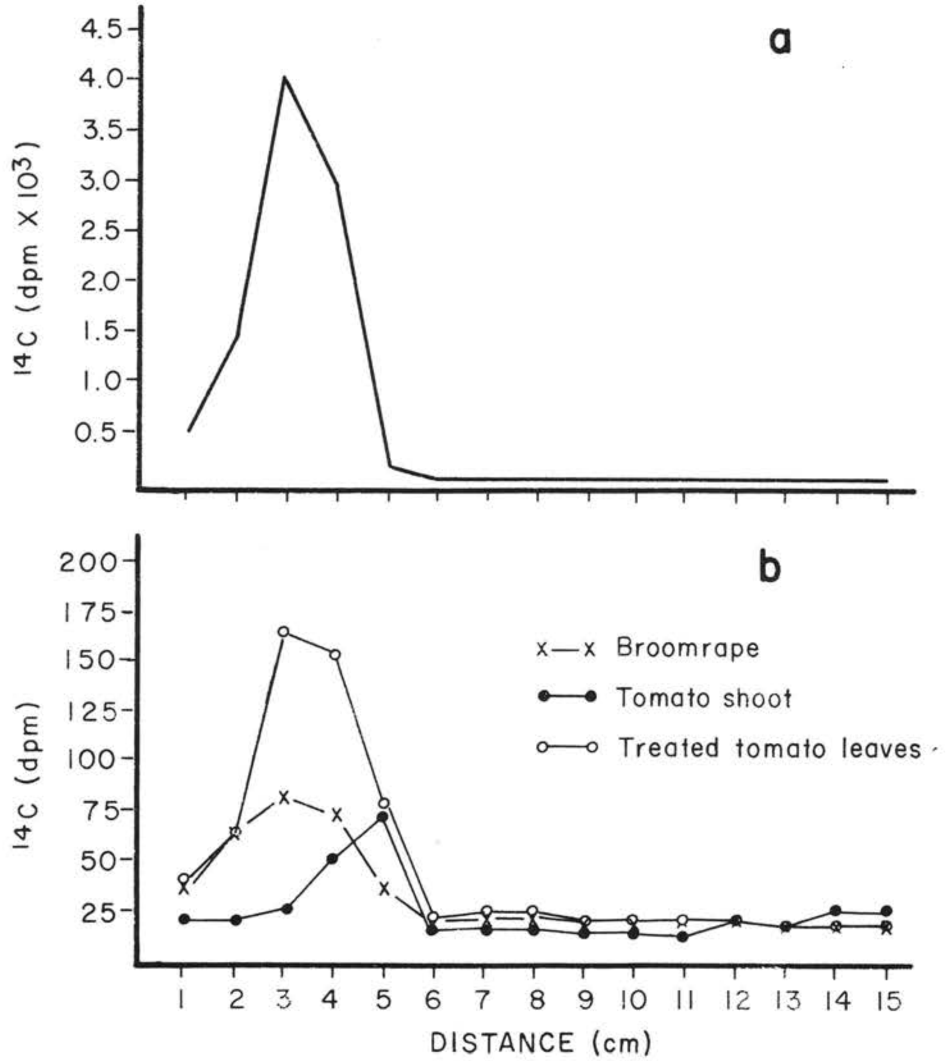

Figure 4. Thin layer chromatographic analysis of (a) ^{14}C-glyphosate standard and (b) ^{14}C-glyphosate in extracts of broomrape, tomato shoots, and treated tomato leaves.

Table 4. Effect of potting media on the growth of tomato plants.

Treatment[a]	Shoot height (cm)	Shoot fresh weight (g)	Root fresh weight (g)
«Rutgers»			
Potting medium A	11.98	3.40	1.36
Potting medium B	12.65	2.65	0.96
Potting medium C	198.75	210.97	9.92
LSD.05	93.55	48.25	2.17
«PUZ 11»			
Potting medium A	18.75	4.33	2.00
Potting medium B	12.28	2.41	1.30
Potting medium C	220.83	243.78	16.58
LSD.05	47.10	55.35	3.59

(a) Potting medium A = clay loam (33.3%), sand (33.3%), Weblite (33.3%).
Potting medium B = clay loam (45%), sand (45%), peat moss (10%).
Potting medium C = vermiculite (40%), Weblite (40%), peat moss (20%).

Table 5. Effect of potting media on the growth of *O. aegyptiaca* on tomato plants.

Treatment[a]	Number of infections	Shoot height (cm)	Fresh weight (g)
«Rutgers»			
Potting medium A	3.42	10.67	2.57
Potting medium B	3.00	10.57	2.22
Potting medium C	0.08	0.00	0.32
LSD. 05	0.90	3.00	0.70
«PUZ 11»			
Potting medium A	4.21	11.57	2.83
Potting medium B	4.71	10.59	2.55
Potting medium C	0.21	0.00	1.05
LSD.05	1.11	2.80	0.69

(a) Potting medium A = clay loam (33.3%), sand (33.3%), Weblite (33.3%).
Potting medium B = clay loam (45%), sand (45%), peat moss (10%).
Potting medium C = vermiculite (40%), Weblite (40%), peat moss (20%).

الملخص

فوي، شستر . ل. وراكش جاين. 1986 . طرق حديثة لمكافحة النباتات المتطفلة . مجلة وقاية النبات العربية 4 : 136 - 144

إن الهالوك والسترايكا من النباتات المتطفلة على جذور كثير من المحاصيل وتسبب لها خسائر كبيرة. إن الطرق المتبعة عادة لمكافحة الأعشاب مثل اتباع الطرق الزراعية المختلفة أو مبيدات الأعشاب هي عموماً غير فعالة وذلك للتقارب البيئي والفسيولوجي بين العائل النباتي والنبات المتطفل كما أن البحث عن المقاومة الوراثية للهالوك في البندورة لم تكن مشجعة. بالرغم من أن مبيدات الأعشاب مثل 2,4D قد استعملت لمكافحة السترايكا، إلا أن الطرق الفعالة لمكافحة الهالوك كانت عن طريق تعقيم التربة بواسطة المدخنات الكيمائية أو الأشعة الشمسية. هناك طريقتان حديثتان أعطتا نتائج مشجعةً لمكافحة النباتات المتطفلة. غاز الأيثيلين أثبت فعالية في إنبات بذور السترايكا بدون وجود العائل ولكنه كان أقل فعالية بالنسبة لبذور الهالوك. مركب السترايكول ومشابهاته كان فعالاً في إنبات بذور الهالوك في غياب إفرازات جذور العائل. كما أن مبيد الأعشاب غلايفوسات كان متخصصاً في تثبيط نمو الهالوك في محصول الفول. الغلايفوسات المشع انتقل من أوراق العائل إلى نموات الهالوك حيث تراكم بتركيزات أعلى من أي جزء في نبات العائل بما في ذلك القمة النامية. إن اتباع الطريقة المتكاملة باستعمال منشطات الأنبات ومبيدات الأعشاب التي تنتقل إلى النباتات المتطفلة (مثل 2,4D في حالة السترايكا والغلايفوسات في حالة الهالوك) قد تكون فاعلة في مكافحة هذه النباتات المتطفلة. يضاف إلى ذلك بأن الريّ المناسب والتغذية الجيدة لنباتات العائل قد تقلل من تطفل الهالوك وبالتالي تقلل من خسارة المحصول.

كلمات مفتاحية : هالوك، سترايكا، طرق مكافحة.

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