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Biology and control measures of *Orobanche*

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ABSTRACT

Orobanche or broomrape obligate, troublesome root parasite which completely depends on the host plant to complete its life cycle. The host plants of *Orobanche* includes crucifers such as oilseed rape (*Brassica* spp.), broad bean (*Vicia faba*) and other crops belonging to Apiaceae, Asteraceae, and Solanaceae families. In India, *Orobanche* has emerged as a major threat to rapeseed mustard production. Many farmers have abandoned the cultivation of mustard under the threat of this parasitic weed. *Orobanche* infestation is mostly confined to major mustard growing states of northern Rajasthan, Haryana, Punjab, Western UP, and North East Madhya Pradesh. In Andhra Pardesh, 50% area under tabacco (40,000 ha) is infested with *Orobanche* and causing 50% crop losses. In Karnataka state, 90% area under tobacco is infested with this weed with 50-60% yield losses. Tomato crop is also infested with *Orobanche* spp. in Mewat and Bhiwani districts of Haryana. Depending upon the extent of infestation, environmental factors, soil fertility, and the crops' response damage from *Orobanche* can range from zero to complete crop failure. *Orobanche aegyptiaca* is the most dominating species in India; however, localized infestation of two other species namely *O. cernua* and *O. ramosa* has also been observed to some extent. In spite of continuous and extensive research by the scientists, no single method for effective and economical management of *Orobanche* is available. Integration of cultural, preventive and chemical methods is required in spite of its costly inputs. Following methods may be adopted in integration fashion: crop rotation with non-host crops like wheat, barley and chickpea depending on the irrigation facilities; delayed sowing (25 October - 10 November) of mustard supplemented with higher seed rate; use of organic manures in combination with increased fertilizer N dose for enhancing crop vigour; two sprays of glyphosate at 25 g/ha at 30 DAS and 50 g/ha at 55 days after sowing provided the crop does not experience any moisture stress at the time of spray; and hand removal/pulling of left-over emerging shoots before flowering to reduce weed seed bank in the soil

Key words: Biology, Cop rotation, Infestation, Mustard, Delayed sowing, Management, Tomato

Parasitic plants belong to 17 different families, but only eight of these contain plants that are considered weeds. Witch weed (*Striga* spp.) and broomrape (*Orobanche* spp.) are the most economically important notorious and destructive parasitic weeds in cultivated crops. In this paper, discussion is focused primarily on biology and management of broomrapes in various crops in context to their effectiveness, advantages, disadvantages, simplicity *etc*.

Orobanche or broomrape (*Orobanche* spp.) locally known as margoja, rukhri, khumbhi or gulli or bhuiphod is a phanerogamic, obligate, troublesome root parasite that lack chlorophyll (Baccarini and Melandri 1967, Saghir *et al.* 1973) and obtain carbon, nutrients, and water through haustoria which connect the parasites with the host vascular system. (Dorr and Kollmann, 1976, Press *et al*. 1986, Punia *et al.* 2012). The attached parasite functions as a strong metabolic sink, often named "super-sink", strongly competing with the host plant for water, mineral nutrition and assimilate absorption and translocation. Depending upon the extent of infestation, environmental factors, soil fertility, and the crops' response damage from *Orobanche* can range from zero to complete crop failure (Dhanapal *et al*. 1996). This parasitic weed has the tendency to proliferate well in coarse textured soils with high pH, low in nitrogen status having poor water holding capacity where the crop cultivation is either rain fed or dependent on sprinkler systems for irrigation.

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Geographical distribution

Broomrapes belong to the family Orobanchaceae. The genus *Orobanche* has more than 150 species (Musselman 1980) among which only a few parasitize agronomic crops. Broomrapes vary in host range, some parasitizing a broad range of crops, whereas others are more specific. The majority of broomrapes are found in the warm and temperate parts of the Northern Hemisphere, especially the Mediterranean region (Sauerborn 1991), but some species have spread to many other parts of the world. Globally, root parasitism of *Orobanche* to numerous important broad-leaf crops including common vetch (*Vicia sativa* L.), crucifers such as oilseed rape (*Brassica* spp.), broad bean (*Vicia faba* L.) and other crops belonging to Apiaceae, Asteraceae, and Solanaceae families have been reported (Goldwasser *et al.* 1997, Hodosy 1981, Ismael and Obeid 1976, Sauerborn 1991), especially in Mediterranean region Southern, Northern and Eastern Europe, Africa, New Zealand, Australia, North, Central and South America. *Orobanche aegyptiaca* occurs mainly in Southeastern Europe, Northeastern Africa, and the Middle East, whereas *O. ramosa*, which is closely related to *O. aegyptiaca*, is mostly found in the Middle East. *O. cernua* and *O. cumana* are primarily distributed in the Middle East, Southern and Eastern Europe, and Northern Africa.

Orobanche ramosa has the widest host range, parasitizing many solanaceous crops such as potato (*Solanum tuberosum* L.), tobacco (*Nicotiana tabacum* L.) and tomato (*Lycopersicon esculentum* Mill.), members of brassicaceae, leguminaceae, and several other families. *Orobanche aegyptiaca*. has a host range similar to that of *O. ramosa*, and is also parasitic on carrot (*Daucus carota*), legumes such as common vetch (*Vicia sativa*), and crucifers including oilseed rape (*Brassica napus*). In the Middle East, *O. crenata*. has a debilitating effect on broad bean (*Vicia faba*), and also attacks carrot. *O. cernua* and *O. cumana* Wallr. are extremely damaging to sunflower (*Helianthus annuus* L.).

In India, *Orobanche* spp. has emerged as a major threat to rapeseed-mustard production in northern Rajasthan, Haryana, Punjab, and north east Madhya Pradesh. In Andhra Pardesh, 50% area under tobacco (40,000 ha) is infested with broomrapes and causing 50% crop losses. In Karnataka, 90% area under tobacco is infested with this weed with 50-60% yield losses in some areas (Dhanapal *et al*. 1998). Yield losses due to *Orobanche* spp. in tobacco growing areas of Tamil Nadu, Gujarat and Maharastra is also reported to be very high. Tomato and brinjal crops are also infested with *Orobanche* spp. in Mewat and Bhiwani districts of Haryana state (Anonymous 2013). Even *Orobanche* infestation on cauliflower and cabbage was observed in Dadri areas of Bhiwani, Haryana.

Weed biology

Plant characteristics: Broomrapes are dicotyledonous annual plants (10-60 cms tall, depending upon the species) and recognized by its yellow to straw coloured stems, bearing yellow, white,or blue, snap dragon like flowers. The leaves are merely triangular scales and both stem and leaves show absence of chlorophylls. Flowers appear in the axils of leaf and are white and tubular. The fruits are capsular and contain numerous tiny black seeds. Broomrapes reproduce only by seeds which are usually dark brown, oval shaped, measure 0.35 x 0.25 mm (Kadry and Tewfic 1956), dust sized weighing 3 to 6 µg (Parker and Riches 1993) and very difficult to recognize without a magnifying microscope. Each capsule contains 600-800 seeds and a single plant may produce more than one lakh seeds depending upon species. Seeds have a pattern of raised ridges (rough surface) and hardened testa, surrounding a fatty endosperm that has an undifferentiated embryo at one end (Kadry and Tewfic 1956). Once ripe, some seed may remain in the capsule but majority of them fall to the ground. Seeds can emerge from as deep as 15 cm below the soil surface. Seed generally remains viable in soil for 10 to 13 years (Brenchley 1920) but the viability can be up to 20 years (Puzilli 1983).

Seed dispersal mechanism: Weed dispersal is mostly confined to contaminated crop seeds owing to poor quarantine services, however, animal grazing, unfermented contaminated manures, wool, fur and farm machinery could be the other sources of seed dissemination. The seeds can easily pass unharmed through animal's alimentary tract and infest the host plants (King 1966). Wind and flowing water contributes negligible to seed dispersal as the seeds are heavy enough to be dispersed away. The seeds do not float in water because of their high specific gravity and once surface tension is broken they sink in water. Thus, wind and floodwater is a low risk vector.

Seed dormancy and germination: Seeds of *Orobanche* generally remain dormant and require a post-harvest ripening period for their germination in response to chemical stimulation (alectrol/orobanchol) from the host plant roots. The stability of the chemical stimulant is very short-lived in the soil. Before germination, seeds must undergo conditioning period under suitable temperature and moisture conditions (Van Hezewijk *et al.* 1993). These conditions ensure that only seeds with in the rhizosphere of an appropriate host root will germinate to contact a host root before exhausting its limited energy resources. Suitable temperatures of conditioning of *Orobanche* seeds are between 15-20 °C for at least 18 days for maximum germination. However, prolonged storage in these conditions causes the seeds to enter secondary dormancy (Van Hezewijk *et al*. 1994a). Increasing storage temperatures increases the percentage of seeds going dormant, there is also some decrease in viability at higher temperatures, with viability reaching zero at 80 °C (Mauromicale *et al*. 2000). The decrease in viability conforms to a sigmoidal curve proportional to moisture and temperature levels (Kebreab and Murdoch, 1999b). For *O. ramosa*, the conditioning period appears to be shorter, with 7 days at 21 °C being sufficient in one trial (Zehar *et al*. 2002).

Optimum temperatures for conditioning and germination are different among broomrape species. Studies on the effect of temperature on germination of *O. aegyptiaca, O. crenata*, and *O. cumana* indicated that every species had a specific optimum temperature range for germination and development which generally reflected its geographical distribution (Sauerborn 1991). Kasasian (1973a) showed that optimum tempera-tures for both conditioning and germination were about 18 °C for *O. crenata* and about 23 °C for *O. ramosa*. Similarly, Weldeghiorghis and Murdoch (1996) reported an optimal temperature of 18 °C for *O. crenata* germination. Van Hezewijk *et al*. (1991b) reported an optimum conditioning temperature of 15 to 20 °C for *O. crenata*. Although temperature is known to influence germination in broomrape, its effect on subsequent development of the parasitic seedling has not been studied. Soil pH (within the normal range of arable soils) has little influence on germination. Germination of *O. crenata* was not reduced at any pH between 5 and 8.5, although subsequent growth of the radicle was favoured by higher pH within this range (Van Hezewijk *et al*. 1994c).

Formation of haustorium and host-parasite attachment : Following the conditioning phase, germinated seed produces a germ tube or radicle in close proximity to the host plant roots that elongates chemotropically and develops an organ of attachment 'the haustorium', which serves as a bridge between the parasitic weed and host plant to drive water, mineral nutrients and carbohydrates from the host plant. The radicle elongates by cell division and attaches itself to the host plant roots mainly in the region of root elongation and absorption (Foy *et al*. 1989, Parker and Riches 1993). The tip of the radicle enlarges, subsequently the haustorial tissue penetrates the epidermis and cortex tissues, and ultimately fuses in to the root vascular system and establishes connections with the host root vascular system by enzymatic degradation, rather than mechanical destruction (Kujit1977, Joel *et al*. 1988, Dorr 1996)

The development of a functional attachment can depend on favourable conditions, such as temperature. *Orobanche* spp. that normally parasitize carrots may fail to get past the initial stage if soil temperatures are too high (Eizenberg *et al*. 2001). *Orobanche* draws its nutrition from the host phloem by direct cell contact. By draining carbohydrates, it can force the host to increase its rate of photosynthesis (Hibberd and Jeschke 2001).

Reproductive phase: The part of the broomrape seedling swells outside the root of host plant to form a tubercle. Within 1-2 weeks, a shoot bud develops on the tubercle producing a flowering spike which elongates, and emerges outside the surface soil. Within a period of 15-20 days, the parasitic weed completes its life cycle and shed thousands of seeds per plant (Pieterse 1979, Foy *et al*. 1989, Holm *et al*. 1997). Findings of Dinesh and Dhanpal (2012) on biology of *O. cernua* revealed that broom rape spikes started emerging above ground from 43-58 days after transplanting, flowering was completed in 7-13 days after emergence while stem drying was completed by 26-38 days after emergence of spike and it completed its life cycle by 37-50 days after emergence.

Management of *Orobanche*

Why *orobanche* is difficult to control?: Compared with non-parasitic weeds, the control of *Orobanche* has been proved to be exceptionally difficult in agricultural crops due to its underground location, close association with host plant roots, complex mechanisms of seed dispersal, germination, and longevity (Cubero and Moreno 1979, Puzzilli 1983, Foy *et al*. 1989, Linke and Saxena 1991a). Because the parasite germinates only in response to host root exudates and then attaches and develops underground on the host plant for the major part of its life, it is inaccessible to conventional control methods such as tillage and herbicide treatments. Furthermore, when the plant becomes visible above ground, much of the damage has already been done and control would be futile. The late appearance of parasite shoots above the soil and the lack of a photosynthetic system as a potential herbicide target does not seems to be practically feasible. The characteristics of *Orobanche* seeds account for much of the difficulty in controlling this parasitic weed. The extremely small seeds produced in vast numbers and seed longevity in fields for 13 years (Parker and Riches 1993) and in Israel up to 35 years (Kleifeld, unpublished), easily dispersal of tiny seeds to near and far by wind, water and livestock are the major factors causing hindrance in developing control measures. Human practices are significantly responsible for distributing *Orobanche* seeds by transporting and using contaminated agricultural vehicles, farm implements and produce containers (by direct seed contamination or through clinging of contaminated soil). Further parasite seed distribution is caused by transportation of contaminated plant material (such as crop seeds and hay) and contaminated soil and manure movement. The use of organic manure from livestock fed with contaminated hay is a cause of further seed dispersal, since the parasite seeds do not lose their viability while passing through animal's digestive systems (Jacobsohn *et al.* 1987).

Several means for managing broomrape have been tried over the years, albeit with somewhat limited effectiveness. Neverthless, following management options may be employed in an integrated manner to manage the orobanche.

Preventive method

The strength of broomrape lies in its ability to form a bank of seeds in the soil. A management or eradication program must aim at reducing this seed bank, while minimising the production of new seeds and their dispersal to new sites. Quarantine is therefore an essential element in control or eradication programs. The best option for winning against broomrapes is avoiding the fight. It is not possible when the fields are already infested with the seeds, but preventive measures must be taken into consideration to avoid spreading the infestation into neighbouring fields.Since massive amounts of tiny seeds are produced continuously for many weeks and are easily dispersed away by air, water and soil, it is almost impossible to prevent seed transfer from a heavily infested field to its close surroundings. In such cases the only preventive method is the discontinuation of growing *Orobanche* host crops, but this does not seems to be practically feasible because of compulsion of farmers to cultivate crops being more suitable and remunerative than other competitive crops under the existing agro-climatic conditions.

Preventive measures could be more effective if the initial specific infestation is sparse and timely precautionary measures are being adopted to counter long distance seed dispersal. The individual farmer could be held responsible, but in most cases the cooperation with neighbours and intervention by local, regional or national agencies is required.

Jacobson (1986) listed some phyto-sanitary measures for avoiding the seed dispersal of *Orobanche* from infested fields to new areas are as under:

- Use healthy and certified planting material of improved varieties free from weed seed contamination.
- Clean farm machinery and equipments to prevent the movement of infested soil to newer areas.
- Use well-rotten decomposed farm yard manure, if needed. Prevent weed seed dispersal by wind or water erosion and farm animals. Since *Orobanche* seeds may pass easily through digestive system of the animals without losing viability, so grazing or feeding hay from infested fields should be prohibited/restricted.
- Do not use irrigation water from *Orobanche* contaminated ponds or reservoirs.
- Practice deep tillage during hot summer months. Placement of weed seeds below 20 cm soil depth was observed to reduce the emergence; however, buried seeds could be brought back by subsequent tillage operations.
- Collect parasite weeds prior to flowering, and do not throw them at random, rather collect at a place and burn.

Cultural method

Crop rotation: A crop rotation system includes *Orobanche* host crops, trap crops and catch crops and non-host crops. Most publications and reviews dealing with *Orobanche* control and management describe crop rotation as a strategy for reducing parasite infestation, but only few suggest concrete guidelines. One exception is the proposal of rice cropping in which flooding throughout the growing season destroys *Orobanche* seeds (Sauerborn and Saxena 1987, Parker and Riches 1993). Theoretically, repeated planting with non-host crops for many seasons should deplete the parasite seed bank in the field. However, we have evidence of very heavy O. *aegyptiaca* infestations of fields after 30-35 years of repeated non-host cultivation and cases of O. *crenata* infestations following more than 20 years of fanning various non-hosts. There is an agreement that monoculture with the same *Orobanche* host crop, or with other hosts of the same *Orobanche* species, rapidly increases *Orobanche* infestation. We have documented evidence that a small spot of infestation could develop into a large-scale heavily infested field as a result of 2-3 years of mono cropping (Kleifeld unpublished).

Crop rotation of mustard with non-host crops like wheat, barley, chickpea *etc*. is the most effective and commonly used management strategy for reducing the weed seed bank in heavily infested areas. The major restriction in adopting crop rotation in long-run is the longer viability of its seeds. Thus, heavy infestations may remain in a field despite absence of host crops for several years. Weed seeds buried in the soil beneath the crop root zone can be brought up to surface soil as a result of subsequent ploughings, germinate and provide competition to the host crop in later years. Frequent planting of susceptible crops on the same field should be avoided and as far as possible grow mustard in alternate years with diverse growing habit genotypes (Braun *et al.* 1984).

Trap and catch crops: Kleifeld *et al.* (1994) justified the importance of using 'trap crops yielding suicidal parasite germination' as a management option for reducing *Orobanche* seed bank in the infested fields. These crops exude stimulants that induce *Orobanche* seed germination but no viable attachment to the host plant roots is established and the weed seedlings withers away and die up and ultimately their seed bank in the soil gets reduced. Resistant varieties that induce parasite seed germination, but do not support the young parasite after attachment, may serve an excellent trap crops as well (Goldwasser *et al.* 1997, Eizenberg 2002). In Indian conditions, at Agricultural Research Station, Nepani (Karnataka), sun hemp and green gram proved to be promising trap crops for *Orobanche cernua* control where tobacco is grown in long growing (Kharif and Rabi) seasons (Dhanapal and Struik 1996). Maize and snap bean has also been found to stimulate germination of *Orobanche* seed bank by 74 and 71%, respectively and helped to increase seed yield of tomato in the 3rd season (Abede *et al.* 2005). Acharya *et al.* (2002) noticed that a local cultivar of *Brassica campestris* has been used as a catch crop in Nepal, reducing the *O. aegyptiaca* seed bank by around 33.35 per cent. Experimental results in Tehran indicated that using trap crops namely sesame, brown indian-hemp, and common flax and black-eyed pea decreased broomrape biomass by 86, 85.3, 75.2, and 74.4 per cent, respectively. Reducing broomrape biomass caused increases in the tomato yield. Meanwhile, sesame, brown Indian hemp, Egyptian clover and mungbean increased total biomass of tomato by 71.4, 67.5, 65.5, and 62.5 per cent, respectively. It was observed that these plants have a great potential to reduce broomrape damage and they can be used in rotation in broomrape infested fields (Sirwan *et al.* 2010).

Krisnamurthy and Rao (1976), Krishnamurthy *et al.* (1977), Abu-lnnaileh (1984), Sauerborn and Saxena (1986) AI-Menoufy (1991), Saxena *et al.* (1994) and Kleifeld *et al.* (1994a) listed some trap crops found effective and may help to reduce seed bank of *Orobanche* spp . Trap crops for *O. crenata* were sorghum *(Sorghum vulgare*), barley *(Hordeum vulgare*), vetch *(Vicia vilosa* var. *dasycarpa)* and purple vetch. *(V. atropurpurea),* clover *(Trifolium alexandrinum),* flax *(Linum usitatissimum),* and coriander *(Coriandrum sativum).*

Trap crops for *O. cernua,* O. *aegyptiaca* and O. *ramosa* were pepper (*Capsicum annuum),* sorghum (*Sorghum bicolor*), cowpea (*Vigna unguiculata*), hemp (*Hibiscus subdariffa*), mungbeans, (*Phaseolus aureus*), flax, alfalfa (lucerne) *(Medicago sativa*), soybean (*Glycine max*), vetches (*Vicia* spp.) and chickpea (*Cicer arietinum*). An additional cultural means for reducing *Orobanche* seed bank in the soil is the use of catch crops *i.e.*, planting an *Orobanche* host crop for inducing parasite seed germination and attachment and that will be destroyed later on by means of light tillage practices or residual soil herbicides. But the use of trap and catch crops to manage this weed is somewhat limited due to (a) enormous amount of *Orobanche* seeds dispersed in the soil and only a small proportion may be exposed to germination stimulants in the rhizosphere (b) feasibility and economics of growing these crops in the existing situations is also a big question mark.

Sowing dates and cropping density: Germination of *Orobanche crenata* tends to be very much reduced below 8 °C and further development is greatly reduced at low temperatures. Delaying the planting date affects *Orobanche* more than its hosts; the delay should be two weeks only from the date optimal for sowing in an uninfested field. However, this method must be adapted for different regions and for different hosts. Early planting dates are beneficial in certain instances. Late planting of mustard (last week of October-first fortnight of November) is observed to be helpful in reducing the parasitism of *Orobanche* a result of specific weed and host plant differential response to low temperatures (Yadav *et al.* 2005) in Indian conditions. Moreover, farmers' perception for late sowing is pessimistic owing to limitation of mustard cultivation to conserved moisture conditions and competition for water utilization for pre-sowing irrigation in wheat; therefore, alternation in sowing time seems to be uncommon and unrealistic approach under Indian context.

Resutls in faba bean showed that shifting sowing from October to November, December or January reduced numbers and dry weight of attached and emerged broomrapes, both *O. crenata* and *O. foetida* (Grenz *et al.* 2005a). Since faba bean development is less susceptible to low temperatures and can be accelerated by increasing day length, pods enter the critical phase of rapid biomass accumulation relatively earlier than parasites. As a result, more parasites and lesser pods are aborted (Grenz *et al.* 2005a) observed a more pronounced effect of late sowing in dry years, which also may indicate the existence of soil moisture-driven effects.

Increased seed rate may reduce competition and number of attachments to some extent but additional cost of seed and other inputs besides providing congenial crop growth environment should also be taken care of while deciding the fate of such interventions.

Host plant resistance/tolerance

Based on inheritance of resistance and variability in pathogenicity, breeding for herbicide resistant crops can be an option towards managing this weed by the mechanism of herbicide translocation through the host plant to suppress and/or kill the obligate parasite. Globally, specific research has been carried out on the development of herbicide tolerant varieties having significant resistance to *Orobanche* infestation in different crops but no such concerted efforts have been put forward to breed such varieties till date in India.

A mustard variety, '*RRN 593*' (Durgamani) earlier reported to be tolerant/resistant to *Orobanche* but it has shown varying degree of limited effectiveness under actual field conditions in the later concluded experiments (Yadav *et al.* 2005), During *Rabi* 2011-12, nine most popular mustard varieties/hybrids, *viz.* '*Korel-432', 'Pro Agro 5444', 'Pioneer 45J21', 'Pioneer 45J42', 'AK 47', 'RH 30', 'RB 50', 'RH 0749'* and '*RH 0406'* were screened for their tolerance against *Orobanche* at village Bidhwan (Bhiwani), Haryana but none of them was found tolerant, however, the differences in seed yield were observed due to differences in their genetic make up and yield potential (Anonymous 2012).

Water management

Less infestation of the parasitic weed has been observed in raya/mustard grown under flooded irrigation compared to sprinkler irrigation or on conserved moisture as the seeds of *Orobanche* do not survive an extended period of inundation. Availability of water and undulating topography are again the limiting factors to practice flooding.

Nutrient management

Higher *Orobanche* infestation and its parasitism on host plants is generally more localized in inherently poor fertility soils dominated by major mustard growing areas of the India. Reports on inhibitory action of increased nitrogen fertilization and manures and compost application on the growth of *Orobanche* are available, however, adequate amount of phosphorus and potash fertilization are also required to raise/ maintain the crop productivity. Application of urea or ammonical form of nitrogen during conditioning and germinating phases has been reported to reduce the germination, radicle length and weed proliferation (Pieterse 1991, Jain and Foy 1992). Low or absence of glutamine synthase (GS) activity in this weed may contribute to sensitivity to N-fertilization and the knowledge about the N-inhibitory mechanism of this weed in relation to their host continues to be elusive, which is central to practical utilization of this strategy.

Urea at 276 and 207 kg/ha, ammonium nitrate, and ammonium sulfate at 207 kg/ha and the goat manure at 20 and 30 t/ha were found most effective in reducing parasitism of *Orobanche* and enhancing growth of tomato plants. Even though drastic reduction of broomrape infestation was obtained, ammonium nitrate and ammonium sulfate at 276 kg/ha seemed to be injurious to tomato plants. As nitrogen rates increased, the numbers and dry weights of shoot of branched broomrape decreased and the yields of tomato increased linearly except the yields obtained from the highest rate of ammonium nitrate and ammonium sulfate. This result indicated that broomrape infestation of tomato decreased with increases of soil nitrogen (Mariam and Rungsit, 2004). The mixtures of chicken manure (20 t/ha) and sulphur (0, 1, 4, 8, and 12 t/ha) at all tested rates significantly reduced the dry weight of *Orobanche* and increased eggplant and potato yield compared with the control (Haidar and Sidahmed 2006).

To confirm the effect of nitrogen fertilization through different sources on *Orobanche* inhibition in mustard, localized field studies were carried out through farmers' participatory approach in Haryana state of India during 2004-2010. Erratic response over the years was observed with respect to weed infestation and population dynamics when nitrogen sources *viz*., ammonium sulphate, calcium nitrate and urea were evaluated alone or in combination with FYM, poultry manure, castor cake, press mud or vermicompost. Use of neem cake/vermi-compost/castor cake and increased N fertilization (120 kg/ha) increased/maintained the crop productivity with parasitism of *Orobanche* by sustaining the host plant growth even with depleted fertility status.

Mechanical and physical methods

Hand weeding/hand pulling: Hand weeding or hand pulling before flowering followed by burning can be an effective and practicable method of checking seed production. Profuse emergence of new inflorescence from below ground plant parts has also been observed within a short span of 7-10 days of hand weeding or hoeing therefore, this warrant for frequent repetitive measures. It only limits the seed production but does not compensate the damage in terms of yield losses. It was reported that three years of hand weeding could control *O. cernua* in tobacco in India (Krishnamurthy and Rao 1976), but the problem remained persistent. Knowing more about the reproduction of *Orobanche* will lead to a better acceptance of hand pulling, especially in areas with recent infestation. However, in combination with other methods, it can reduce the seed bank very efficiently (FAO 2008).

Tillage/ intercultivation: Deep tillage during summer months causes seed desiccation and places them below the root zone preventing seed germination to some extent, but again the longer viability (up to 20 years) of weed seeds raises a question mark in long run.

Deep inversion plowing and fire: Placement of seeds at 20-cm depth was observed to cause little emergence of *O. cernua* (Krishnamurthy *et al.* 1987). However, the buried seeds could be brought up by subsequent tillage. Parker and Riches (1993) propose burning of residue from infested crops to reduce carry over of broomrape seeds back to the soil.

Soil solarization: Covering moist soil (with or without minimum disturbances at planting) with white or black polyethylene sheet for a month or so can increase the soil temperature by almost 10 °C (48-57 °C) compared to uncovered soil resulting in killing of *Orobanche* seeds that are in the imbibed state; therefore, soil must be wet at the time of treatment (Jacobsohn *et al.* 1980, Braun *et al.* 1987, Sauerborn and Saxena 1987). Seeds of *O. ramosa* can survive 35 days at 50 °C in dry air, but are quickly killed by temperatures of 40 °C when wet. This technique has been used successfully on cropping land in many countries around the world like Middle East with an endemic *Orobanche* problem, as a pre-planting treatment for tomato, carrot, eggplant, faba beans and lentils. Soil solarization has been proven to be the most effective methods in controlling broomrape in open crops fields (Haidar and Sidahmad 2000). But high cost of polyethylene, appropriate machinery and cloud-free sunny days may restrict its use on larger scale (Foy *et al.* 1989). Soil solarization coupled with no-till was found better in controlling *Orobanche c*ompared to solarization under conventional tillage. This approach has attracted the interest in many warm-climate countries because of its effectiveness, simplicity and safety for humans, plants, and the environment.

Biological methods

There are some reports on managing *Orobanche* through biological perpetuation of a fly, *Phytomyza orobanchia* (Girling *et al.* 1979, Trenchev 1981, Klyueva and Pamuchki 1982, Mihajlovic 1986). Tillage may bury broomrape stalks, containing *Phytomyza* pupae, deeper in the soil, thus preventing emergence of adults. Crop-specific insecticides and parasites of *Phytomyza* may reduce the fly population considerably. Crop rotations may also have negative impact on the survival mechanism of *Phytomyza*. With deep ploughing hibernating pupae can be destroyed and/or buried and thus prevent insect emergence. Managing weed infestations to some extent through mycoherbicides have been reported by Hodosy (1981) and Bedi and Donchev (1991).

Fungi such as *Trichoderma viridae* and *Psuedomonas inflorescence* were tested at farmers' fields in village Hasan (Bhiwani) and CCS HAU Hisar during 2010-11, but these were found ineffective against *Orobanche* in mustard (Anonymous 2011). Inoculation of fungus *Fusarium oxysporum* sp. *orthoceras* in the field resulted 90% control of *Orobanche* in sunflower (Bedi and Donchav 1991, Bedi 1994, Sauerborn *et al.* 1994) or tomato (Hodosy 1981). Relative high soil humidity and soil temperatures are required for the development of soil fungi. More research is needed to develop a reliable biological method under Indian conditions.

Chemical methods

During the last decades, some potential useful chemical interventions have become available for the control of parasitic weeds (Garcia-Torres 1998). However, this form of control is complicated by a number of factors including: (i) it is effective only as a prophylactic treatment, since in most cases we do not know the infestation level; (ii) the parasite is directly connected to the host; (iii) if the herbicide is to be applied to the parasite through the conductive tissues of its host, the host must be selective to the herbicide without reducing its phytotoxicity; (iv) herbicides have low persistence and the parasite can often continuously germinate throughout the season, developing new infections (Perez-de-Luque *et al.* 2010).

These are Soil fumigants, residual soil applied herbicides and post-emergence applied herbicides have been reported to possess potential to control *Orobanche*.

Soil fumigants: Earlier, soil fumigation with methyl bromide (MB) prior to planting was used (Wilhelm, 1958) but World Health Organization (WHO) and Agricultural authorities ultimately banned the use of methyl bromide for fumigation purpose because of its negative environmental effects (United Nations Environmental Protection Service 1992). Fumigation by compounds that release methyl isothiocyanate was suggested for *Orobanche* eradication. Metham sodium, applied directly by injection or by chemigation via irrigation systems into the soil, or dazomet incorporated mechanically into the soil, followed by irrigation that releases the toxic ingredient, were found to be very effective for *Orobanche* control. Methylisothiocyanate was effective in deeper soil layers, but very ineffective on the surface, because of its rapid evaporation (Goldwasser *et al.* 1995). The difficulties in application of 1,3-dichloropropen and the narrow pest control range limit its utilization to small-scale intensive farming only.

Residual soil applied herbicides: Several reports are being published on the beneficial effect of mechanically incorporated herbicides belonging to dinitroanilines, sulfonyl areas, substituted ureas group showing host crop selectivity and significant soil residuality for better control of *Orobanche* (Parker and Riches 1993).

Seed treatment: Seed treatments with imidazolinones have proven to be effective for controlling *O. crenata* in faba bean. Coating sunflower seed with 2 kg/ha and soaking the seeds in 50% of pronamide has lowered broomrape shoot dry weight and increased the yield of sunflower from 2.14 (control) to 2.85 t/ha in coated seed and from 1.24 (control) to 1.79 t/ha in soaked seeds (Sanchez *et al.* 2003). The sulfonylureas also have the advantage of selectivity for preventing emergence of broomrape growing on broad-leaved weeds in a non-host cereal crop: 3 g/ha metsulfuron-methyl, 15 g/ha chlorsulfuron or 22.5 g/ha triasulfuron gave 100% control of *O. ramosa* without damage to wheat or barley crops (Matthews 2002). This may be due to their direct effect on *Orobanche* and to their reduction of broad leaved weed hosts.

Soil and foilar applied herbicides: Chlorsulfuron applied at 3.75 g/ha directly to the soil completely controlled O. *aegyptiaca* (Hershenhom *et al*. 1998b). This herbicide, which has a longer soil activity than most other sulfonylureas, was applied directly into the soil by "chemigation" (delivering of the herbicide through irrigation water) to tomato transplants after establishment in the field. The phytotoxic contact of the herbicides with the host foliage was avoided by using very dilute solutions, and by washing of the herbicide into the soil by additional sprinkler irrigation. Three split applications of 2.5 g/ha chlorsulfuron through sprinkler irrigation, starting at 14 days after tomato planting and at intervals of 10-14 days followed at each application by 300 m^3/ha irrigation, controlled 80-90% *Orobanche* without phytotoxicity to the tomato crop. Single or double split application, application through a drip system or at high volume spray did not sufficiently control *Orobanche* throughout the growing season (Hershenhom *et al*. 1998c). Aplication of of chlorsulfuron, through drip-irrigation systems to control late season *Orobanche* emergence around drip emitters in tomato effectively controlled *Orobanche* emergence (Kleifeld *et al.* 1999), but its efficacy was inconsistent in other trials.

Sulfonylurea herbicide is registered worldwide for pre- and post-emergence of grass and broad-leaf weeds in wheat. Though sulfosulfuron was initially developed and registered for controlling an array of grass and broad leaf weeds in wheat, its selectiveness to some broadleaf crop species has recently led to its registration for weed control in potato in Poland (Anonymous 1995, Hatzios 1998). In extensive research conducted in Israel, sulfosulfuron has proven to be highly efficient and selective for O. *aegyptiaca* control (Eizenberg *et al*. 2001b). While chlorsulfuron and triasulfuron were most effective when applied by chemigation, sulfosulfuron can be sprayed on tomato foliage followed by sprinkler irrigation to wash the herbicide into the soil where it is absorbed directly by the young parasites or via the tomato host roots. Greenhouse experiments with activated charcoal suggested that the herbicide acts mainly through the soil and not by translocation through the host tomato plant. To achieve good parasite control, high herbicide rates at early developmental stages of the parasite were needed, that is two or three applications of 37.5 g/ha starting two weeks after tomato planting and repeated at two week intervals. Study conducted in Chickballapura district of Karnataka state (India) revealed effectiveness of pre-emergence sulfosulfuron at 75 g/ha in controlling *Orobanche* in tomato grown under irrigated conditions (Dinesha *et al.* 2012)

The imidazolinones are ALS-inhibiting herbicides with the same mode of action and similar characteristics as the sulfonylurea herbicides. These herbicides are used pre-emergence and post-emergence for control of annual and perennial grass and broadleaf weeds.

Various legumes are resistant to some of the imidazolinone herbicides and this resistance has led to selective use of these herbicides in certain legume crops. Legumes are tolerant to imazapyr because they can metabolize it to an inactive form (Shaner 1989). Garcia Torres *et al.* (1998) reported selective *O. crenata* control in faba bean by pre-emergence and post-emergence applications of imazethapyr, imazapyr and imazaquin. In our studies we have found that crops belonging to other botanical families are imidazolinone- tolerant: split application with various imidazolinone herbicides on potato, sunflower and parsley foliage selectively controlled *O. ramosa, O. cumana,* and *O. crenata,* respectively. In these cases the herbicides were extensively translocated to the attached root parasite directly through the host plant, in contrast to the mode of control with sulfonylurea herbicides that act on the parasite directly through the soil. This method eliminates the need for irrigation following application.

Three doses of imazapic at 4.5 g/ha, sprayed at 2 weeks after crop emergence and reapplied at 2 weeks intervals, followed by its deliverance in potato root zone by sprinkler irrigation prevented *Orobanche* infestation. Although these treatments increased crop vigour and potato yield but potato tuber quality was severely damaged in light sandy soil (Goldwasser *et al.* 2001). Split application of imazapic at 2.5-5.0 g/ha applied on 5-7 leaf parsely before first cutting and on young new growth after each cutting provided effective and selective control of *O. crenata* and *O. aegyptiaca* (Gold Wasser 2003)

Imazethapyr herbicide was developed for the control of many broadleaf and grass weeds by pre-plant, pre-plant incorporated and post-emergence applications in soybean, peanuts and edible legumes (Ahrens 1994) and parsely. This herbicide was the first of the imidazolinone group to be registered for *Orobanche* control. A post emergence application of 20 g/ha on garden and field pea *(Pisum sativum* and *Pisum arvense,* respectively) one month after planting and an additional treatment of 20-40 g/ha two weeks later, was selective to pea and efficient in *Orobanche* control (Jacobsohn *et al.* 1998). Imazethapyr has been registered at these rates for post-emergence *O. crenata* control in peas in Israel and at 75-100 g/ha pre-emergence applications for *O. crenata* control in faba bean in Spain (Garcia-Torres *et a*l. 1998). There are reports of some promising results of *O. crenata* control by faba bean and pea seed treatments with imazethapyr (Jurado-Exposito *et al.* 1996, 1997, 1999).

Rimsulfuron, a sulfonylurea herbicide, was developed originally for early post-emergence control of broad-leaved and grass weeds in com (Hatzios 1998). The selectivity of this herbicide to the Solanaceae family led to its registration for weed control in tomato and potato (Reinke *et al.* 1991). A new sulfonylurea herbicide selective to tomato when applied through drip irrigation in tomato root zone controlled *O. aegyptiaca*. Since rimsulfuron's residual soil activity is short, so repeated applications were necessary for season long weed control (Kleifield *et al.* 1994). Three repeated doses of rimsulfuron at 12.5 g/ha each followed by irrigation, sprayed on potato foliage two weeks after crop emergence and re-applied at two week intervals effectively and selectively controlled *O. aegyptiaca* with no damage to potato yield or tuber quality (Goldwasser *et al.* 2001). Rimsulfuron achieved efficient *Orobanche* control in potato fields but not in tomato fields because potato fields were sprinkler irrigated while tomato fields were drip-irrigated and the herbicide was rapidly leached around the drip emitters.

Some of the locally available common herbicides at different concentrations, *viz.* pendimethalin (PE) 1000 g/ha, linuron (PE) l000g ha, trifluralin (PPI) 1000 g/ha, fluchloralin (PPI) 1000 g/ha, metribuzin (PE/PPI) 175-200 g/ha, sulfosulfuron (PE) 5-10 g/ha, oxyfluorfen (PE) 125-175 g/ha, thiazopyr (PE) 240 g/ha, isoproturon (PE/PPI) 500-1000 g/ha, chlorsulfuron (PE/PPI) 2-6 g/ha and triasulfuron (PE/PPI) 5-10 g/ha were tested in field trials conducted at farmers' fields in Bhiwani district and KVK, Mahendergarh (Haryana) by scientists of CCS HAU Hisar from 2000-2008. These herbicdes were found inconsistent in their efficacy against the parasitic weed over the years and sometimes even showed phyto-toxicity to the mustard crop or both (Yadav *et al.* 2005).

In pot culture (2004-05), seed immersed with chlorsulfuron (0.05-0.1% solution) or triasulfuron (0.15-0.30% solution) for 5-10 minutes resulted in severe crop phyto-toxicity just after emergence. However, seed coating with chlorsulfuron, triasulfuron or sulfosulfuron at 0.05-0.1 mg/kg seed proved safe for crop. Since there was no germination of *Orobanche* in pots filled with infested soil (may be due to consistently high moisture and poor aeration), these results were further exploited under field conditions. Results of experiments conducted from 2005-08 under farmers' management practices revealed that seed treatment of mustard with triasulfuron, sulfosulfuron and chlorsulfuron have been found to delay the emergence and attachment of *Orobanche* but the results were inconsistent over the years. Over-dosing of the herbicide seed treatment some times caused poor germination and suppression in crop growth (Punia *et al.* 2012).

***Orobanche* control with glyphosate:** Foy *et al.* (1989) and Kleifeld *et al.* (1999) reported selectivity to various herbicides against broomrape in a variety of crops. Parker and Riches (1993) earlier reported the glyphosate use on limited areas for *Orobanche* control in broad bean, carrot and celery. Kukula and Masri (1984), Van Hezewijk *et al.* (1991) and Jain and Foy (1992) have also demonstrated the effectiveness of systemic herbicides and fertilizer application in increasing the broomrape control efficacy. Host crops which are tolerant to glyphosate are fababean, carrot, cabbage and Celery. Tomato and pea are extremely sensitive to glyphosate (Jacobson and levy 1986). All these reports favour the use of glyphosate as a potential herbicide for *Orobanche* management, but there is dire need to conduct research particularly under real time farm situations to determine the optimum period and dose of herbicide application during which the parasite is most sensitive and the mustard crop is most tolerant. Since glyphosate is a broad spectrum non-selective foliar applied herbicide, its efficacy in managing *Orobanche* could be quite useful but at the same time the selectivity of this herbicide is limited and needs critical precautionary measures to have effective results.

A study undertaken at Hisar (Haryana) to evaluate the efficacy and to standardize the dose and time of glyphosate application against the parasitic weed *Orobanche* in mustard (*Brassica juncea*) from 2006-

2010, indicated that higher dose of glyphosate at early crop stages sometimes caused localized phytotoxicity on mustard plant viewing marginal leaf chlorosis, slow leaf growth, interveinal leaf bleaching, and/or slight elongation of apical leaves but the crop recovered within 7-10 days after spray with no yield penalty. Single application of herbicide though provided effective control of the weed; however, late emergence of new shoots were observed in the later half of crop growth, ultimately causing reduction in seed yield and adding weed seeds to the soil. Glyphosate applied twice at 25 g/ha at 30 DAS followed by 50 g/ha at 55 DAS provided 65-85% control of *Orobanche* even up to harvest (without any crop injury) with yield improvement from 12 to 41% over the traditional farmers' practice (Table 1) in different years of the study (Punia *et al.* 2010, Punia and Singh 2012). Similar findings on the control of *Orobanche* in mustard through herbicide application were also reported by the scientists at Gwalior and Bikaner (DWSR 2009).

The tolerance of plants to glyphosate was mainly attributed to readily degradation of this herbicide to non-toxic metabolites. It is readily absorbed by the mustard plant foliage and translocated to the young parasites attached to the roots, leaves and meristems, thereby inhibiting the synthesis of enzyme 5-enolpyruvylshikimate-3-phosphate (EPSP) synthase that leads to the production of aromatic amino acids (phenylalanine, tyrosine and tryptophan) and thus protein synthesis and growth (Amerhein *et al.* 1980). These results were further validated in large scale multi-locational trials conducted at different locations through farmers' participatory approach in Haryana during the *Rabi* seasons of 2010-11 to 2013-14. A total of 157 demonstrations were conducted in mustard growing areas of Haryana covering 267 ha area and it was observed that overall 74.4% (range 40-95%) reduction in *Orobanche* weed infestation with 15.1 per cent (range 13.9-16.3%) yield superiority was noticed with glyphosate treated plots (25 g/ha at 30DAS followed by 50 g/ha at 55-60 DAS) when compared with the farmers' practice of one hoeing at 25-30 DAS (Table 2).

There were reports on the effectiveness of glyphosate in tomato, tobacco, faba beans, and other crops under greenhouse conditions elsewhere, but have not been yet reported from India, particularly under field conditions. Foliar spray of glyphosate twice, 25 g/ha at 30 DAS followed by 50 g/ha at 55 DAS may be helpful in reducing the *Orobanche* infestation by checking the further increase in weed seed bank without any crop suppression, but at the same time requires certain precautionary measures in its use. Since most of the mustard cultivation in India is limited to light textured soil having inherent poor fertility status and water holding capacity, care should be taken that the crop should not suffer from any moisture stress at the time of foliar spray, therefore, the fields should be ir-

Table 1. Effect of glyphosate application on *Orobanche* management and seed yield of mustard

Treatment	Dose (g/ha)	Time of application (DAS)	Reduction in *Orobanche* (%)			Crop phyto-toxicity (%)	Seed yield (t/ha)
			70 DAS	120 DAS	Harvest		
Glyphosate	25	30 and 55	98 (96-100)	94 (84-96)	82 (72-92)	-	1.67
Glyphosate	50	30 and 55	98 (93-100)	90 (85-95)	86 (70-88)	10-20	1.63
Glyphosate	25	30 and 55	59 (52-70)	41 (30-48)	30 (56-52)	-	1.53
Glyphosate	25	30 and 55	92 (86-98)	71 (64-82)	42 (38-50)	10-20	1.50
Farmer's practice (one hoeing)	-	30	-	-	-	-	1.40

Figures in parentheses indicate range of the treatment effect (mean of 4 years)

Table 2. Comparative performance of glyphosate application *vis-à-vis* farmers' practice for *Orobanche* management in mustard

Year	No. of trials	Area covered (ha)	*Orobanche* control (%)	Seed yield (t/ha)		Percent increase in yield over farmers practice
				Treated*	Farmer's practice*	
2010-11	12	5	82 (70-95)	1.72 (1.40-2.10)	1.49 (1.20-1.95)	15.5
2011-12	24	20	79 (65-90)	1.59 (1.20-2.20)	1.37 (0.90-1.80)	16.3
2012-13	86	156	72 (55-90)	1.75 (1.25-2.25)	1.54 (1.00-1.95)	13.9
2013-14	35	82	63 (40-90)	1.65 (1.25-2.40)	1.44 (1.10-2.10)	14.6

*25 g/ha at 30 DAS and 50 g/ha at 55-60 DAS, **one hoeing at 25-30 DAS

Figures in parentheses indicate range of the treatment effect on *Orobanche* control and mustard seed yield rigated 2-3 days prior to herbicide application. The proper time and dose of herbicide should also be taken care of to have better efficacy of herbicide application as repetitive/higher/lower than the recommended dose may lead to adverse impact on mustard crop or may result in development of herbicide-resistant weeds (Shoeran *et al*. 2014). The present study has shown that glyphosate, if used at desired concentrations can be very helpful in reducing the parasitic weed infestation while affording tolerance to the mustard crop. This would definitely obviate the *Orobanche* seed bank to further increase as well as improve the overall productivity and economic well being of the mustard growing farmers' fraternity.

Other approaches

Putting 1-2 drops of diesel oil, boiling water and kerosene oil on each shoot have also been suggested for the control of this weed (Krishnamurthy *et al*. 1976, Linke and Saxena 1991b). Similarly, oils of gingelly, groundnut, palm, sunflower, safflower, niger, castor, linseed, coconut, tobacco, eucalyptus, pongamia, soybean, rice bran *etc*. applied 2-3 drops on the top of heads have been reported to kill broomrape shoots within 2-4 days, but with less effect on flowering shoots (Krishnamurthy and Chari 1991, Krishnamurthy and Nagarajan 1991b, Krishnamurthy 1992). Not all oils were quite effective, but they have the advantage of not being phytotoxic to the host plant. However, these techniques have practical problems and 3-4 repeated applications on emerging shoots at an interval of 4-5 days is required for its effective control. All these aforesaid oils causes only localized desiccation and prevent seed setting but later on emergence of other shoots was observed.

Based on two years (2003-05) field trials conducted in Haryana, the author is also of the view that application of kerosene, diesel and soybean oil, caused only localized desiccation and blackening of inflorescence (3-4 cm from the top), however, profuse emergence and regeneration of new shoots were observed after 10 days of chemical treatment. Moreover, application of these oils is tedious if not impossible, besides being ineffective and uneconomic (Yadav *et al.* 2005). Spraying under the influence of dense crop canopy restrict the movement of applicator. Desired liquid flow abilty through spray nozzles due to high viscosity of spraying oils is another area of concern to get the desired results. Use of plant hole application of neem cake at 200 kg/ha at 30 DAT or post-emergence application of imazethapyr at 30 g/ha at 55 DAT has been suggested to control *Orobanche* in tobacco under Western zone of Tamil Nadu in India (AICRPWC 2013).

Genetically engineered herbicide-resistant crops

The recent development of transgenic herbicide-resistant crops, and especially those resistant to amino-acid inhibiting herbicides, has opened up new opportunities (Joel *et al.* 1995). The use of these transgenic crops for parasitic plant control will intensify in future with the identification and utilization of additional herbicide resistant genes. Concern may also arise regarding the possible gene transfer from transgenic crop plants to wild plants, although different ways to overcome these concerns have been proposed (Gressel 2004). Complete control of *0. aegyptiaca* was achieved when modified acetolactate synthase enzyme induced transgenic tobacco was treated with chlorsulfuron. Excellent control of broomrape with glyphosate application in oilseed rape having modified enolphosphate-shikimate phosphate synthase (EPSP) and with asulam resistant tobacco plants having modified dihydropteroate synthase (methyl carbamate) has also been well documented. However, a variety of tomato engineered for resistance to glufosinate, an inhibitor of GS, was infested with broomrape in spite of application of glufosinate. Similar cases have been reported in sunflower also

Aviv *et al.* (2002) engineered a mutant AALS gene into carrot, allowing the control of broomrape by imazapyr (an imidazolinone ALS inhibitor). Several tobacco cultivars transformed with a mutant acetohydroxy acid synthase (AHAS) 3R gene (isolated from a sulfonylurea resistant *Brassica napus* cell line) were resistant to the herbicide chlorsulfuron (Slavov *et al.* 2005). A very low percentage of chlorsulfuron (from 0.1 to 4 %) of its active ingredient that reached the plant roots was sufficient to kill the parasite at an early developmental stage after two treatments (Slavov *et al.* 2005).

Parasitic weeds will rapidly evolve resistance to herbicides because of their prolific seed production. Therefore, resistance to glyphosate, asulam, chlorosulfuron, or imazapyr will eventually appear. Therefore, herbicide resistance crops should be wisely used or combined with other control methods, and new resistant crops continually developed (Radi 2007)

Dissemination and evaluation of technology

A training programme on the use of glyphosate for effective control of *Orobanche* in faba bean was propagated in Morocco for more than 15 years, but only 15 per cent of the interviewed extension workers were able to demonstrate the correct description of its application technology. Therefore, training of extension staff is as an important component in facilitating effective advisory work and in assisting farmers' knowledge, attitude and beliefs towards assessing and adopting a new technology intervention in right and effective manner. Apart from technical knowledge, extension workers may also require trainings on the appropriate use of extension material and on how to improve their communication skills.

Conclusions

In spite of continuous and extensive research by the plant breeders, weed scientists and plant protectionists, *Orobanche* spp. are still causing serious problems in large number of crops worldwide and are aggravating in many areas. The nature of *Orobanche* makes its control extremely difficult, costly, or environmentally hazardous. Several methods for managing broomrapes include hand weeding, deep ploughing, crop rotation, alteration in seeding windows and fertilizer N scheduling, the application of organic manures and biofertilizers, chemical seed treatment, and kerosene/soybean oil droplets spray; however, they are inconsistent and have limited effectiveness. No single technique provides complete control of *Orobanche*. Physical methods are very useful to prevent the *Orobanche* but are tedious, time-consuming and costly and prevent only seed setting not yield losses. Chemical, agronomic control methods and host resistance appear to be the most appropriate measures when available and affordable. Moreover, some biological and crop resistance approaches are promising but they are too expensive and control may not be complete and still need more research. Integration of cultural, preventive and biological and chemical methods is required even though it is very costly to deplete weed seed bank and to avoid further dispersal. However, these integrated programmes are practiced only on a small scale in a few countries because of cost and technical problems. Therefore, it is reasonable to hypothesize that GMO approaches will be adopted for parasitic weed control in the near future.

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