Broomrapes (Orobanche spp.) the Challenge and Management: A review

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ABSTRACT

Broomrapes (Orobanche spp.) are among the most damaging parasitic weeds to agriculture. The subsite themselves on the roots of a wide range of cultivated and wild-grown plant species of different plant families. These parasites are varied in morphology and plant hosts they attack, although they share a large number of host species. Certain Orobanche species are more specialized to plant species of specific growth forms such as fruit and forestry trees. All Orobanche species are obligatory parasites because they lack chlorophyll and thus heterotrophic completely depend on host plants for food and/or water absorbed through specialized organs called a haustoria. The present review introduces information on biology, ecology, distribution, host/parasite relationship, economic importance, and management of the most important Orobanche species widely spread in Jordan and worldwide that cause great yield loss of different economic crops and devastate yield totally under heavy infestation. Recent literature and overview information on methods of control followed in Jordan and different parts of the world are included and discussed.

Keywords: Parasitic weeds, Orobanche spp., Broomrapes, host species, managements

INTRODUCTION

Orobanchaceae is mainly a northern warm and temperate zones family. Orobanche spp. is reported from more than 58 countries. The family Orobancheaceae consists of 89 genera including 2061 species (Nickrent, 2008; Gevezova et al., 2012). The majority of species are facultative or obligate root parasites that subsist on broad-leaf plants, and exhaust hosts’ nutrients, minerals, and water. The main representative genus is Orobanche, a destructive root parasite that includes more than 160 parasitic species of most crop destructive and problematic species are branched broomrape (O. ramosa), Egyptian broomrape (O. aegyptiaca), nodding broomrape (O. cernua), crenate broomrape (O. crenata) and small broomrape (O. minor); some workers add the sunflower broomrape (O. cumana) and fetid broomrape (O. foetida) (Parker, 2009). The main hosts of these parasites are species of Leguminosae, Apiaceae, and Asteraceae for O. crenata, sunflower (Helianthus annuus) for O. Cumana, Solanaceae for O. cernua, Leguminosae for O. foetida, clover (Trifolium spp.), and alfalfa (Medicago sativa) for O. minor, and many families, including the Solanaceae, Cucurbitaceae, and Brassicaceae for O. ramosa and O. aegyptiaca (Qasem, 2009; Parker, 2012; Punia, 2014). Different Orobanche species may also attack species of different plant families. Orobanche minor was reported to parasitize plants from at least 16 orders of monocots and dicots (Thorogood et al., 2009). Parasite shoot/s appear above the soil almost at the
end of its life cycles and only for flowering and seed production (Fernández-Aparicio et al., 2016).

Orobanche spp. is holo-parasites, annual in duration, prolific seed producers, seeds are tiny measuring 0.2 by 0.3mm, with a minute amount of reserved food. A single shoot produces 270,000 seeds that are widely disseminated by wind and survive in the soil for 20 to 30 years.

Differences exist between species in flower and seed size, flower color, and other morphological variations.

**GERMINATION AND DEVELOPMENT**

Orobanche seeds must undergo a period after ripening which may extend for 18-24 months, followed by a conditioning period, before responding to germination stimulants. Some chemicals can shorten this period (Song et al., 2005) enhance the response of Orobanche spp. seeds to the artificial germination stimulant GR24 (Song et al., 2006).

Seeds germinate when became close to or in contact with host roots, but are triggered by receiving host germination stimulants through root exudates. The optimal temperature for germination is 20-25°C and 20/10°C for attachment. Light enhanced O. ramosa germination but inhibited germination of O. crenata, pH, calcium, or phosphate ions affect germination stimulants and microbes inactivate stimulants in the soil. Some nonhost root exudates, ethylene, gibberellic acid, and calcium hypochlorite enhance parasite seed germination (Qasem, 2006a).

**CONTACT AND ATTACHMENT**

Orobanche germinated seed extends a radicle (germination tube) that moves toward the host root system in a chemotropic response or bending movement in response to inhibitory chemicals in the host root exudates. Successful contact needs the radical locates host root, haustoria development, penetration into the host root, and connection between vascular systems of the parasite and host plant. Upon the contact sticky papillae adhere the parasite to the host root surface. Penetration occurs mainly by mechanical pressure on the host cells and hydrolytic enzymatic action (Veronesi et al., 2007). The primary haustoria and the tubercles are the major connecting organs. After attachment, the radicle doesn’t act anymore. The haustoria swell forms tubercles or nodules and connect with the vascular system of host plants and s absorption of the required materials. The parasite functions as a powerful super sink strongly deprive water, mineral nutrients, and carbohydrates. Orobanche accumulates mannitol that lowers parasite osmotic potential much more negatively than the host. Upon haustorial growth, an underground tuber develops, shoot bud differentiates, elongates, and emerges above the soil only for flowering and seeding.

Orobanche seedlings have no chlorophyll and in absence of a suitable host, they soon shrivel and die. the life cycle of the parasite involves two phases, the conditioningtart, important for leaching germination inhibitors from parasite seeds and germination stimulates or related substances are accumulating, and the second phase is seedling attachment to the host root system and the start of true parasitism. The latter phase is further divided into the hypogeal stage occurs below the soil level and the epigeal stage during which the vegetative organ grows rapidly and produces reproductive organs above the soil. Emergence, flowering, and seeding of the parasite may take 15 to 18 days.

**ECONOMIC IMPORTANCE**

Orobanche spp. are problematic and destructive parasites to agriculture in different parts of the world and difficult to control (Rubiales and Fernández-Aparicio, 2012; Habimana et al., 2014; Fernández-Aparicio et al., 2016). They attack a large number of cultivated and wild species (Parker and Riches, 1993; Qasem, 2009) and can totally destroy crops under heavy infestation. (Jain and Foy, 1992; Fernández-Aparicio1 et al., 2016).

Orobanche crenata and O. ramosa are the most common and cause yield loss of more than 75% (Kamel, 2005). In the Mediterranean and West Asia, about 16 million ha has been reported as threatened. Yield loss was estimated at hundreds of millions of dollars annually affecting the life of 100
million farmers. Aly (2007) reported annual losses estimation in food crop caused by Orobanche spp. in the Middle East at billion dollars. Under heavy infestation, crop yields may be completely lost (Barney et al., 2005; Qasem, 2019 and 2020a) especially in marginal areas or in dry regions (Silverside, 2002a, b; Barney et al., 2005).

Orobanche cernua severely attacks tomato, tobacco, and sunflower. Yield loss in tobacco ranges from 30 - 70% (Dhanapal, 1996), affects yield and quality and heavy infestations destroy 25% of the crop in India (Mariam and Suwanketnikom, 2004) and is exhaustive to beans (Phaseolus sp.) in Italy. Orobanche causes considerable yield losses in tobacco, clover, tomatoes (Lycopersicon esculentum Mill.), sunflowers, and broad beans (Vicia faba L.) in the USA (Ristau, 2001). Yield losses due to O. crenata may reach as high as 75-100% in certain parts of the Sudan and Ethiopia (ICARDA, 2006) while seed-yield losses caused by O. foetida in broadband reached 95% (Bouraoui et al., 2016).

Orobanche species may also serve as hosts or carriers for viruses, bacteria, and polyphagous insects. Orobanche ramosa L. was mentioned as a new host for Pseudomonas syringae PV. Tomato (Nevena and Senka, 1997) and has been reported as a novel host that facilitates replication and processing of viroids such as PSTVd (Vachev et al., 2010).

**CONTROL.**

Different strategies have been proposed for Orobanche spp. control (Rubiales and Fernández-Aparicio, 2012; Punia, 2014; Fernández-Aparicio et al., 2016; Samejima and Sugimoto, 2018) including prevention; agricultural such as planting date, crop rotation with trap and catch crops (Al-Menoufi, 1991), nitrogenous (Jain and Foy, 1992) and mineral fertilizers and managed fallow; physical methods such as the use of soil plastic mulch, soil solarization with or without animal manure fermentation, flooding, organic material, and burning; breeding for resistant cultivars (Foy et al., 1988; Cubero and Hernandez, 1991; Qasem and Kasrawi, 1995); mechanical including hand weeding, weeding after harvest and deep plowing; biological using insects and fungi (Parker and Riches, 1993) such as Fusarium oxysporum (Cubero et al. 1999; Lu et al. 1999; Thomas et al. 1999a,b); and chemical control methods using soil fumigants (Foy et al., 1989), germination stimulants (Qasem, 2006b) and herbicides.

In the last two decades, sulfonylurea and imidazolinone herbicides were introduced for parasites control in tomatoes and results have been reported on selective control of O. aegyptiaca by chlorsulfuron and triasulfuron (Ghannam et al., 2012) and O. ramosa by chlorsulfuron (Qasem, 1998). Persistence, toxicity, and low selectivity of these and imidazoliones with the high cost and public concern on human health and environment necessitate the search for alternatives. Genetic engineering has also been proposed. However, complete control methods are not yet available (Qasem, 2006a; Rubiales and Fernández-Aparicio, 2012; Habimana et al., 2014; Disciglio et al., 2016; Fernández-Aparicio et al., 2016). Below are details on methods employed for Orobanche spp. control.

**Prevention Methods**

Orobanche seeds spread by different means from contaminated crop seeds to the workers (Qasem, 2006b). Prevention is an important approach, i.e., sowing clean washed crop seeds. Contaminated containers should not be used and prevention of parasite seeds dispersal between fields is necessary (Kebede and Ayana, 2018). National and international trade of crop seeds should be strictly subjected to quarantine regulations. Prevention of animals feeding on parasitic weeds or controlling their movement. Orobanche ramosa subsp. mutelii (F.W. Shultz) Cout. was reported to transmit by sheep wool or by pass-through gastrointestinal tract (Ginman et al., 2015). In addition, it is important to eradicate parasitic weeds in newly infested fields. Hand weeding and burning of parasite shoots is necessary to prevent seed spread and control of weeds in general during fallow years and before seeding is needed to prevent parasitic weed on wild or weed species.
Cultural and Mechanical Methods

These include:

Land Preparation

Deep plowing was proposed for O. ramosa in tomato (Labrada and Perez, 1988) and O. cernua in tobacco (Khot et al., 1987). Zero and minimum tillage increased broad band infestation by O. crenata (Kukula and Masri, 1984) and perennial weeds while 40-50 cm deep tillage reduced Orobanche by 80-90% in three year-period (Cited by Kasasian, 1971).

Planting or Sowing Date

Van Hezewijk et al. (1987) and Raaimakers et al. (1988) confirmed severe infestation of early plantings of broadbean and lentil by O. crenata. Munoz et al. (1993) reported that the emergence period of O. cernua increased as the sowing date was delayed. Sunflower yield was higher at earlier sowing dates and may be recommended in Orobanche-infested areas under mild Mediterranean climate. Germination of O. crenata tends to be zero below 8°C. Delaying the planting date affects Orobanche more than its hosts (Habimana et al., 2014). For effective control of O. cernua, broadbean cv. Giza 402 should be sown around mid. November in Egypt without glyphosate application and with zero tillage (Nassib et al., 1984). Early sowing of peas was effective in reducing Orobanche incidence (Pirani et al., 1993). However, the change of sowing date seems not highly promising under certain conditions. Orobanche cumana on sunflower appeared earlier at late than early planting dates. Orobanche shoots per plant were fewer when sunflower planting was late (Aydin and Mutlu, 1996). In another study, parasitism of O. crenata was decreased with later sowing dates, while better results were obtained with resistant varieties and late sowing (Sillero et al., 1999). Perez-de-Luque et al., (2001) came also to the same conclusion.

Planting Depth

The position of Orobanche seeds in the soil plays a major role in determining parasitism. Mohamed-Ahmed and Drennan (1994) reported significant failure in O. ramosa emergence when crop plants were grown from seeds planted at 11-cm or deeper compared with seeds planted at 3-4 cm depth. Eltayeb et al. (2000) found that O. ramosa seeds placed 10 cm deep resulted in heavy infestation compared to those placed at 15 cm thus tomato seedlings plated at 15 cm, reduced parasite infestation.

Hand Weeding

An option available to farmers worldwide and cheap in populated poor societies. Hand-pulling of O. cernua in tobacco resulted in almost complete control after 3 years (Krishnamurthy and Rao, 1976). Clean cultivation followed by hand weeding or hoeing was commonly recommended for Orobanche control and systematically before flowering for several years until exhaustion of the seed bank (http://www.wssa.net/subpages/weed/larrymitich/Orobanche.html). Weeding of the parasites is not very promising in heavily infested areas, is time-consuming, tedious, only workable at a long-term practice, and can cause injuries to the root system. However, it is an important tool of control, in fields with starting infestation and when repeated 3-4 times a season at 4-5 days intervals was effective in eradicating the parasite within 5-6 years (Krishnamurthy, 1992).

Crop Rotation with Trap/Catch Crops

Trap Species

Cultural methods usually involve the inclusion of trap or catch crops in rotation. Crop rotation with non-host crops especially with trap species is of great advantage (Eltayeb et al., 2000). Schnell et al. (1994) reported legume crops to cause a great reduction in O. crenata seed banks and resistance has been found both in cultivated and wild grown legumes (Rubiales et al., 1999) including different Lathyrus spp. which may be used as trap crops (Sillero et al., 2001).

Trap species is a false host that stimulates parasite seed germination but is not parasitized. It exhausts the parasite seed bank in integration with other methods of parasite management while traps species or stimulatory natural
chemicals (Yoneyama et al., 1998a,b; Evidente et al., 2010; Daniel et al., 2011) may be incorporated in parasite management. Sunhemp (C. juncea L.) and green gram (Vigna radiata L.) are promising trap crops in bidi tobacco. Peppers (Capsicum annuum L.) in rotation with tobacco te to reduce broomrape seed infestations (https://wssa.net/wp-content/themes/WSSA/WorldOfWeeds/orobanche.html) and pepper roots stimulated germination of 22-26% of nodding Orobanche seeds with no attachments. In pepper intercropping with tomato, a Four-fold increase in the number of nodding Orobanche was observed on tomato roots compared with the number of parasites on tomato roots planted separately. Vicia villosa subsp. Da Scarpa in rotation with lentil, chickpea, and broad bean kept O. crenata infestation at a low level (Schnell et al., 1996). Flax (Linum usitatissimum L.) in two successive winter seasons or one summer cropping with Phaseolus aureus Roxb. (Vigna radiata) reduced early infestation of O. aegyptiaca and significantly increased tomato growth and production (Kleifeld et al., 1994). Coat buttons (Tridax procumbens L.), and hairy beggar-ticks (Bidens pilosa L.) have been also reported to reduce parasite infestation (http://www.wssa.net/subpages/weed/larrymitich/Orobanche.e.html).

Some highly successful species in rotation included sesame, brown Indian hemp, common flax, and black-eyed pea (Vigna unguiculata (L.) Walp.) that reduced broomrape biomass and increased tomato yield. Sesame, brown Indian hemp, Egyptian clover, and mungbean increased tomato biomass (Babaei et al., 2010). Flax was most effective and reduced O. crenata in lentil fields. Flax and sugarcane significantly reduced O. crenata in a rotation with broad bean (Abou-Salama, 1995). Broccoli reduced the shot number of the same parasite species by 48% and 39% in two years (Aksoy et al., 2016). Different species stimulated seed germination of Orobanche spp. by more than 90%, and extracts of many plant species may be considered as a trap, cover, catch species, or a source of natural germination stimulants for these parasites (Babaei et al., 2010; Ma et al., 2012; Qasem, 2019). However, heavily infested fields should be planted with trap species for 2 or 3 years to exhaust the parasite seed banks.

Different cultivated or wild species with great potential to stimulate Orobanche seed germination have been reported including sorghum (Sorghum vulgare Pers.), barley (Hordeum vulgare L.), and vetch (Vicia dasycarpa spp. villosa) for O. crenata (Linke et al., 1991); bean, sorghum, maize, and cucumber for O. ramosa (Labrada and Perez, 1988) and sorghum, cowpea, chili, hemp, mung bean, flax, lucerne, soybean and chickpea for O. cernua (Krishnamurthy and Rao, 1976; Krishnamurthy et al., 1977) while flax was the most potent trap crop. Linke et al., (1991) showed a significant reduction in O. crenata infestation after three years of growing V. dasycarpa spp. villosa. Forage legumes have been recommended as trap crops to reduce broomrape’s seed bank (Saxena et al., 1994). Sillero et al., (2001) reported the possible use of Lathyrus choranthus as a trap crop since permitted a very low emergence of broomrape shoots but allowed a relatively high establishment of the parasite with low susceptibility to Orobanche.

The non-suitable host crops of O. cernua including chili, sorghum, cowpea, Phaseolus aconitifolius, and Hibiscus sabdariffa L. stimulated germination of the parasite at a high level. Sesame (Sesamum indicum L.) stimulated germination but without offering further growth and development (Krishnamurthy and Chandwani, 1975). Root diffusate of L. usitatissimum, C. annuum, S. indicum, and Trifolium alexandrinum L. enhanced Orobanche seed germination, but the germinated seeds failed to attach to their root systems (Krishnamurthy et al., 1977; Al-Menoufi, 1991). Strong induced germination of O. cernua seeds was obtained using V. radiata and C. juncea (Dhanapal et al., 1998). Boulet et al., (2001) reported Avena sativa ssp. sterilis, Ammi majus, Solanum nigrum, and Anagallis arvensis possessed different levels of resistance that led to the death of O. ramosa. Rodriguez-Ojeda et al. (2001) found that corn, sorghum, millet, cotton, rice, eggplant, and cauliflower stimulated germination of O. cumana seeds.
Avenaol was reported as a germination stimulant from *Avena strigosa* (Kim *et al.*, 2014). Zemrag and Bajja (2001) reported fenugreek and coriander reduced the number of attached parasites per host plant and disturbed their development.

Maize and snap bean as traps for *O. ramosa* under intercropping, the depleted seed bank of *O. ramosa* and *O. cernua* by 72.5% per season (Abebe *et al.*, 2005), and significantly increased tomato yield. Dongola (2006) reported that rotation of tomato with onion reduced *O. ramosa* infestation by 90-95% and increased tomato yield by 60%. Qasem (2019) found that the highest *O. ramosa* shoot number was found on tomato followed by *Anethum graveolens* L., *C. vulgaris*, *Cucumis melo* var. *flexuosus* L., *Pimpinella anisum* L., *S. indicum*, *Solanum elaegnifolium* Cav., *S. vulgare*, *Spinacia oleracea* L., and *T. alexandrinum* but lowest after *Brassica oleracea* L. var. *Italica* plenck, *Brassica rapa* L. var. *Rapa*, *C. annuum*, *Capsicum frutescens* L., *Cicer arietinum* L., *Citrullus colocynthis* (L.) Schrad., *Cucurbita maxima* Duch., *Cuminum cyminum* L., *H. vulgare*, *L. usitatissimum* L., *Spinacia oleracea* L. cv. Epinard grand, and *Vigna sinensis* (L.) Savi. Parasite dry weight per shoot was lowest on tomato grown after *C. arietinum*, *C. frutescens*, *Cucumis melo* L., *H. sabdariffa*, *P. anisum*, and *T. alexandrinum* but highest after *Cichorium endivia* L. var. *crispum* Lam., *Peganum harmala* L., *S. oleracea* cv. Epinard grand and *Zea mays* L. Tomato shoot dry weight increased by 126% over parasite-free control following *Ecballium elaterium* (L.) A. Rich. and parasite infestation reduced by 56% of the Orobanche-infested control. High tomato growth and best parasite control (73% reduction) were obtained after *V. sinensis*. *H. sabdariffa*, *H. vulgare*, and *S. vulgare* reduced both Orobanche infestation and tomato yield.

Trap crops may effectively reduce Orobanche seed bank, and could be used as a part of an integrated Orobanche control approach. Good results with effective trap crops may not be efficient, possibly not practicable for ecological/economical reasons. Development of the parasite on weeds needs to be eliminated, while important trap crops to reduce the seed bank for different parasitic weeds are not available. The success of trap crops in the exhausting soil seed bank of the parasite may be highly questionable under severe infestation or require a fairly long period for effective control which may not be economically feasible in certain growing systems.

**Catch Species**

These are true hosts that induce parasite seed germination and parasitized. They are infected or enhanced parasite seed germination and attachment but hinder its development by mechanical, physiological, or chemical factors. These must be sacrificed, harvested, plowed, or destroyed after 6-8 weeks, mostly at vegetative and before parasite emergence or latest before parasite flowering. Catch crops are likely used as preceding crops and have to be closely planted. This method of control, however, is costly because of additional labor, is not usable if the growing season is short, and needs good mechanization because of the possible loss of a growing period. However, cultivation of all hosts should be easy and inexpensive, germination stimulation should be high, their elimination is not problematic, and they are as high in yield as fodder or green manure. Acharya *et al.* (2002) reported that two successive crops of toria (*Brassica campestris* var. *toria*) reduced *O. aegyptiaca* seed bank by 20.9% and 26.2% for both crops, respectively. The optimum density of toria plants required for significant reduction of *O. aegyptiaca* seed bank was about 140 plants/m².

**Intercropping with Trap or Catch Species**

Al-Menoufi and Adam (1998) concluded possible use of *Trigonella foenum-graecum*, *Lupinus termis*, *Coriandrum sativum*, and *Brassica rapa* L. in intercropping with broad bean or tomato to reduce Orobanche on host roots. Many of these crops, however, were found attacked by *O. ramosa* (Qasem and Foy, 2007). Abbes *et al.* (2019) reported that intercropping with fenugreek enhanced seed yield and reduced *O. foetida* infestation in the broadbean. Inhibition of *O. crenata* seed germination by allelochemicals released by
fenugreek roots was suggested as the mechanism for the reduction in parasite infection (Fernández-Aparicio et al., 2008c). The use of a variety of mixtures of plant species is considered as a possible strategy to affect Orobanche-host interaction by combining certain host species with different degrees of susceptibility (Bouhatous and Jacquard, 1994). Experimentation in Egypt reported a significant reduction of O. crenata infection on broad bean and pea inter-cropped with berseem clover. Mini-rhizotron experiments demonstrated reduction in O. crenata infection on pea, lentil and chickpea (Fernández-Aparicio et al., 2010a).

Garlic in peas resulted in the least Orobanche emergence, while higher seed yield was obtained when peas were mixed with onion. Complete elimination of Orobanche emergence was achieved in a mixture with black cumin (Hassan, 1998). Maximum germination of O. cernua was obtained when the parasite seeds were exposed to the green gram, sun hemp, and sesamum followed by black gram and sunflower (Dhanapal et al., 1998). Arabidopsis thaliana induced seed germination of O. aegyptiaca, O. minor, and O. ramosa at a rate of 87, 72, and 67% of maximum seed germination, respectively (Goldwasser et al., 2000). Root exudates of corn, sorghum, millet, cotton, rice, eggplant, and cauliflower induced seed germination of O. cumana under laboratory conditions, and none was infected (Rodriguez-Ojeda et al., 2001).

Certain weeds include Avena sterilis, Conyza canadensis, Ammi majus, Datura stramonium, Cichorium endivia, Anagallis arvensis, and Solanum nigrum supported O. ramosa attachment but different resistance levels were observed and led later to the death of the parasite (Boulet et al., 2001). These authors suggested using these weeds as trap species for O. ramosa control. Qasem and Foy (2007) screened a large number of weed species for infection with O. ramosa and found many were heavily infected and others were nonhosts. However, a wide variation in tomato infestation was observed when was planted after these weeds. Orobanche crenata infection on broad bean and pea was reduced when intercropped with oat. Pot and rhizotron experiments confirmed the reduction of infection in faba bean intercropped with cereals. The inhibition in seed germination by allelochemicals released by cereal roots is the mechanism for the reduction of O. crenata infection (Fernández-Aparicio et al., 2007). Fernández-Aparicio et al. (2013) reported inhibition of O. crenata seed germination and radicle growth by cereals allelochemicals. Intercrops with oat (A. sativa L.), fenugreek (T. foenum-graecum), or berseem clover (T. alexandrinum) can reduce O. crenata infection on legumes because of allelopathy influence (Fernández-Aparicio et al. 2008b, c, 2010a). Parasite seed germination was inhibited in presence of oat or fenugreek roots suggesting the release of toxic substances. Trigoxazonane in fenugreek (Evidente et al. 2007) or benzoxazolinones (Fernández-Aparicio, unpublished) from oat root exudates may be responsible for the inhibition obtained.

Intercropping of canola with wheat could significantly reduce Phelipanche aegyptiaca growth depending on the type of wheat genotype. The inhibitory potential of wild wheat genotypes was stronger than cultivated genotypes (Razavifar et al., 2017). However, the success of trap crops may be highly questionable under severe infestation or may require a fairly long period for effective control which may not be economically feasible under certain growing systems.

**Plant Residues and Soil Cover**

Surface applied and pre-plant incorporated wheat and barley straw mulch residues significantly reduced O. ramosa infestation and growth in potatoes (Haidar et al., 1995a). Olive cake for Orobanche spp. control on different crops has been also reported (Ghosheh et al., 1999, 2006; Aybeke, 2016, Disciglio et al., 2016; 2018). Peas were not infected with O. crenata in the olive cake-containing media at any parasite inoculation density while the sporadic infection was detected on faba bean and tomato in media inoculated by O. crenata and O. lavandulacea on both crops, respectively. Aybeke (2016) found that olive cake composting achieved success against O. cernua in sunflower and was suggested to
improve and provide regular plant development in arid lands of intense Orobanche infestation. Disciglio et al., (2016) tested 12 agronomical, chemical, biological, and biotechnological strategies for Phelipanche ramosa (L.) Pomel control in processing tomato but none provided complete control of the parasite. Later Disciglio et al., (2018) reported olive mill wastewater as effective against Ph. ramosa infestation and increased tomato productive parameters.

Qasem (2020) reported effective control of O. ramosa in potted tomato using olive mill wastewater and olive cake but the first was more selective and effective against the parasite. Qasem (2002), reported high allelopathic activity of shoot residues of certain weed species and root exudates of different weed and crop species on seed germination of O. ramosa in tomato grown under glasshouse conditions.

### Soil Mulch and Solarization

Soil solarization is a nonselective method that works against all weeds including Orobanche spp. and soil pests. Plastic mulch was found effective in controlling Orobanche sp. (Tsybul’skaya and Skoklyuk, 1978). Only soil solarization has eliminated Orobanche and the majority of weeds from the treated plots. The yield has increased from 7.8 t/ha of untreated control plots to 21.08 t/ha on plots treated with solarization (Abdalla and Dabrowski, 2000). Orobanche aegyptiaca was controlled with solar heating using polyethylene clear film 0.03 mm thick left in place for 30-50 days in the summer (Cartia, 1985). The efficacy of this technique, however, may be improved when combined with organic supplementation, with positive effects on the yield of greenhouse tomatoes. Solar heating followed by mulching was promising for the control of O. ramosa and increased eggplant yield with glyphosate used at 40g/ha (Braun et al., 1985). Sauerborn and Saxena (1987) obtained corresponding results against O. crenata in faba bean and lentil in Syria, 40 days' treatment lead to > 90% control in both crops; and similarly Abdel-Rahim et al. (1988) controlled O. crenata in faba bean in Egypt by 10 weeks treatment. Soil solarization reduced the population and incidence of Orobanche (Sauerborn et al., 1989). Black plastic mulch completely controlled O. ramosa and O. aegyptiaca in tomato and eggplant (Vouzounis and Americanos, 1998). It was also effective in controlling O. cernua in tobacco (Meti and Hosmani, 1994), and O. crenata in broad bean (Abdalla, 1999).

Solarization killed Orobanche seeds at 0 cm depth, but in combination with chicken manure seeds at soil depths from 0-10cm were killed (Haidar and Sidahmed, 2000). Solarization for 2-6 weeks with or without chicken manure significantly reduced weed growth and infestation in cabbage. Pre-plant composting with fresh manure under plastic mulch in the planting rows causes Orobanche seeds to lose viability within six weeks and reduced O. ramosa infestation on many vegetables. Two consecutive years of soil solarization are needed under the Mediterranean conditions to completely eradicate the broomrape seed banks in highly infested soil (Mauro et al., 2015). There is a residual effect over several years following this treatment, resulting in increased crop yields. This method, however, is not applicable in general for economic reasons, but under certain conditions, where water is available for irrigation.

### Mineral Fertilization/Organic Matter

Orobanche tends to associate with less fertile soil conditions. High levels of chicken manure and fertilizer, especially nitrogen, have a suppressive effect. Nitrogen fertilizer reduced O. crenata (Kukula and Masri, 1984). Ammonium nitrate alone or in combination with potassium phosphate completely inhibited infection of tomato by O. aegyptiaca (Jain and Foy, 1987). Ammonium nitrate with potassium phosphate or ammonium phosphate alone was most effective in reducing parasitism and enhancing the growth of tomato plants in O. aegyptiaca infested fields (Mariat and Suwanketnikom, 2004). Low rates of ammonium sulfate reduced O. crenata infestation without hurting V. faba (Jain and Foy, 1992). Ammonium-N-based liquid fertilizer in direct contact with O. crenata adversely
affected parasite germination potential. The effect was dependent on the rate of N-used (Eplee et al., 1994). The number of the emerged and dry weight of O. ramosa in tomatoes decreased with an increase in N level, while an increase in the level of K had an opposite effect (Demirkan and Nemli, 1994).

Ammonium sulfate (8mM) applied during the conditioning period reduced germination of O. crenata, 4mM ammonium sulfate strongly inhibited germination when applied after conditioning during the germination phase. Urea (8mM) reduced germination to a limited extent (Van Hezewijk and Verkleu, 1996). Radicle lengths of O. aegyptiaca and O. ramosa were inhibited by ammonium nitrate and ammonium chloride than by potassium nitrate and both parasite species were different in their sensitivity to nutrients (Nandula et al., 1996). Ammonium form was more inhibitory to Orobanche spp. than nitrate (Westwood and Foy, 1999). Germination of O. aegyptiaca and O. oxyloba was strongly inhibited by copper and vanadium, while boron inhibited radicle elongation of O. oxyloba at 25ug/liter (Zaitoun et al., 1996) and foliar spray of 0.5% boric acid 60 days after V. faba sowing completely controlled O. crenata (Hassan and Farrag, 1982). Elongation of O. aegyptiaca and O. oxyloba was inhibited by Zn and Mo (Zaitoun et al., 1996). In potatoes, chicken manure alone or with sulfur was effective in reducing O. ramosa growth and infestation early in the season. The mixtures of chicken manure and sulfur at 8 and 12 t/ha significantly reduced late Orobanche infestation in eggplant (Haidar and Sidahmed, 2006).

Flooding

Soil flooding for weeks killed parasite seeds in the soil (Goldwasser and Rodenburg, 2014). Under rainfed agriculture, water shortage usually could not permit this method. Regular irrigation will support the host to compensate for the attack of the parasite to a certain extent. However, water lodging inhibited Orobanche emergence when applied for more than 6 weeks (Mohamed-Ahmed and Drennan, 1994).

Resistant and Tolerances

The most outstanding are sunflower varieties resistant to O. cernua/Cumana but resistance has often been overcome by new, more virulent ‘races’ of the parasite in many countries.

Sauerborn et al. (2002) induced resistance in sunflower against O. cumana using benzo (1,2,3) thiadiazole-7-carbothioic acid S-methyl ester (BTH), the active ingredient of Bion®, under controlled growth chamber conditions. In sunflower, the parasite was effectively controlled using two resistant hybrids, Favorite (Ypsilon S.A.) and Odil (Pioneer) (Syka and Economou, 2005).

Sunflower cultivar M15 from Argentina showed complete resistance to race E of O. cumana (Miladinovic et al., 2012) Line no. 16693 cv. Armavirskii 3497 was completely resistant to different races of O. cumana, and the inbred line, AB-VL-8, developed from interspecific hybridization with the rough sunflower (Helianthus divaricatus) was fully resistant to races higher than F (Imerovski et al., 2016; Cvejic et al., 2012). Successful identification of quantitative trait loci (QTLs) for O. cumana resistance in the sunflower has been reported (Louarn et al., 2016; Akhtouch et al., 2016).

Two cultivars of faba bean (Giza 429 and Giza 674) with good resistance to O. crenata have been released in Egypt (Khalil et al., 1993). a new genotype (X-843) derived from Giza 402, was reported to have a good yield and recommended for release in north Egypt (Saber et al., 1999). A high-yielding faba bean cultivar ‘Baraca’ has been developed in Spain, with a high level of resistance to O. crenata (Cubero et al., 1994). However, several faba bean cultivars with resistance to O. crenata have been released, all used Giza 402 as the main donor of resistance (Fernández-Aparicio et al., 2012; Rubiales et al., 2016) and resistant varieties against more than two Orobanche/Phelipanche spp. were used in the field (Trabelsi et al., 2015, 2016).

High levels of resistance to O. cernata were observed in accessions of wild lentil Lens ervoides, Lens odemensis, and Lens Orientalis. Resistance proved to be mainly due to early
hampered tubercle formation (Fernández-Aparicio et al., 2009a).

Chickpea genotypes namely, FLIP 98-22C, Nayer, and Beja 1, showed partial resistance to O. foetida which was due to incompatibility (Nefzi et al., 2016).

Five resistant sesame genotypes with an important trait were identified to have Ph. aegyptiaca formed tubercles on their roots but no parasite shoots emerged (Teimouri et al., 2016).

A highly O. crenata-resistant pea line, named ROR12, was identified (Bardaro et al., 2016; Pavan et al., 2016). The resistance mechanism may be due to the low release or production of germination stimulants but this does not affect the host yield of the resistant line. Resistance to O. crenata has been detected in wild peas (Lathyrus cicera) which were found due to a low induction of germination, incompatibility, and escape parasite attack due to precocity or small root biomass (Fernández-Aparicio and Rubiales, 2010). Out of 52 grass, pea accessions screened to O. crenata under field conditions, early and very late-maturing accessions were less infected (Fernández-Aparicio et al., 2012). Nine more accessions would have true genetic resistance that was not dependent on the short and long growth length.

Resistance of five oilseed rape (Brassica napus L.) cultivars namely; Darmor, Campo, Adrianna, Expert, and Shakira was ascribed to incompatibility or based on a low induction of germination under field conditions (Gauthier et al., 2012). In tomatoes, some resistance to Orobanche was reported from the Russian cultivars "Ora", cv. Gibrid-88 and cv. Bolgarskii (Mukumov and Faizieva, 1977).

High to moderately resistance to O. ramosa was obtained in the cultivars Tiny Tim, Acora, Cestor, Promodora, Orient, Red Alert and Lycopersicon pimpinellifolium LA 1478 with Tiny Tim showed the highest level of resistance (Qasem and Kasrawi, 1995). Kacan and Tursun, (2012) reported several tomato cultivars resistant to P. aegyptiaca in Turkey and Tokasi et al. (2014) reported other varieties to resist the same parasite under field conditions in Iran. The SL-ORT1 mutant of tomato was shown to be resistant to high concentrations of P. aegyptiaca seeds, and to another three broomrape species: Ph. ramosa, O. cernua, and O. crenata (Dor et al., 2010). The fast-neutron-mutagenized tomato mutant SL-ORT1 was found to be highly resistant to various Phelipanche and Orobanche spp. SL-ORT1 resistance results from its inability to produce and secrete natural germination stimulants to the rhizosphere (Dor et al., 2011). Tomato cultivar ‘Red setter tilling’ which is genetically based on a cultivar ‘Red setter’ is resistant to Ph. ramosa because of a reduction in the synthesis of the germination stimulant (Disciglio et al., 2016).

Buschmann et al., (2005) reported on differences in tobacco cultivars to Orobanche ramosa. Populations' Dark air-cured tobacco cultivars were the least susceptible to broomrape populations. Tobacco genotypes, two ones, TB 22 and Kramograd NHH 659, did not show any susceptibility to P. aegyptiaca in pot experiments (Darvishzadeh, 2016).

**Biological Methods**

The following natural enemies could be used against Orobanche spp.

**Insects**

Tóth et al. (2005) reported 22 species of 10 families on Orobanche in Slovakia but only Phytomyza orobanchia Kalt. and Chyliza extenuata, and two moths, Diaphora mendica and Celypha spp. caused significant damage. Chyliza extenuata as a root feeder and D. mendica as a seed capsule feeder is very promising.

Phytomyza orobanchia has been successfully applied on a large scale in the former Soviet Union to control O. cumana and O. cernua (Kapralov, 1974). The insect attacks parasite seed capsules and causes a great reduction in seed production ranging between 29-94% depending on Orobanche species. However, the phytophagous insects on Orobanche including Phytomyza orobanchia (Diptera) occur in most Orobanche-infested regions. Phytomyza larvae feed on the shoots and especially on the capsules of Orobanche spp. (Klein et al.,
The insect can damage Orobanche seriously and may reduce seed production by 30% under natural infestation in Syria and by 89% in Egypt.

Other insects reported attacking Orobanche including Psila species at the larval stage that attack stem of O. minor and C. extenuate. Eulocastra argentisparsa Hampson, Smicronyx spp., Ophiomyia strigalis Spencer have been also reported on Orobanche in India and Africa, but are polyphagous (Kroschel et al. 1999; Traoré et al., 1999; Klein and Kroschel, 2002).

In general, P. orobanchia and Smicronyx cyaneus Gyll. (Coleoptera, Curculionidae) are of great importance in biocontrol of Orobanche spp. (Klein and Kroschel, 2002).

**Bacteria**

In Petri-dish and pot experiments, Mabrouk et al. (2007) found that inoculation of peas with two (P.SOM and P.1236) of the five strains induced a significant decrease in O. crenata seed germination and the number of tubercles on pea roots. An endophytic bacterium, Pseudomonas strain PhelS10, originating from tomato roots, suppressed Ph. aegyptiaca seed germination and reduced the number of the same parasitic species on tomato roots (Kruh, 2017). Rubialis et al. (2018) reported an almost 80% reduction in P. aegyptiaca seed germination and a significant reduction in its parasitism was achieved due to the presence of a Pseudomonas sp. strain on tomato roots.

Chickpea roots inoculated with Rhizobium sp. strain PehAZM reduced the total number of O. foetida by up to 90% (Mabrouk et al., 2016). Bouraoui et al. (2016) reported that despite the high seed yield reduction of faba bean caused by O. foetida, the inoculated crop with Mat strain of rhizobia showed an average yield three-fold higher than the control. Two Rhizobium leguminosarum strains (Mateur and Bouselem) were selected as potential inoculants to protect faba beans against O. foetida and to promote the host’s growth in pot and rhizotron experiments (Bouraoui et al., 2012). Inoculation of chickpeas with Rhizobium strains significantly decreased O. crenata and O. foetida seed germination and several tubercles (Hemissi et al., 2013; Mabrouk and Belhadj, 2014).

**Fungi**

Sixty-two fungi species were isolated from different Orobanche species (Thomas et al., 1999a), eight of these showed pathogenicity to Orobanche, and four belonging to the genus Fusarium, among which F. oxysporum f. sp. Orthocera (1999a) and Fusarium arthrosporioides (Amsellem et al., 2000) are thought to be developed as mycoherbicides. Babalola (2010) reported that F. arthrosporioides killed 56% of O. aegyptiaca tubercles infesting tomatoes while its mycelia had no damage effects on tomato roots. Other reports mentioned 16 fungi species attack different Orobanche species including O. aegyptiaca, O. cernua, O. crenata, and O. ramosa but only Ulocladium, Fusarium (F. oxysporum var. orthoceras; F. orobanchas), Alternaria, and Rhizoctonia solani proved highly effective and selective against O. ramosa in tomato and reduced infestation by 80%, Ulocladium atrum as effective as a biocontrol agent for O. crenata at high humidity.

Fusarium arthrosporioides E4a and F. oxysporum E1d, as well as strains of bacteria, were isolated from diseased, juvenile, Orobanche flower stalks. They are pathogenic to O. aegyptiaca, O. crenata, and O. ramosa. Tóth et al. (2005) reported different pathogens observed on O. alba and O. flav.

In Russia, good results were obtained adding F. oxysporum into the planting holes of watermelon (Product F). However, investigations concentrate on F. oxysporum f. sp. orthoceras, reported control O. cumana in sunflower by 90%, and O. ramosa and O. aegyptiaca were also susceptible (Bedi, 1994). The same fungus decreased Orobanche infestation to tobacco by 75.23% and increased crop yield by 80.5% (Mazaheri et al., 1991). It was also reported to control O. cumana by 74-90% in naturally infested fields (Bedi, 1992) and recommended for O. cumana control in sunflower (Bedi and Donchev, 1995; Bedi and Sauerborn, 1999).
The microconidia or air-dried chlamydospore were formulated as granules with wheat flour and kolin (Pesta) as a rich biomass of F. oxysporum Schlecht. f. sp. orthoceras (Appel and Wollenw.) and found effective against O. cumana in sunflower (Müller-Stöver et al., 2002) and reduced parasite shoot emergence by 64% (Müller-Stöver et al., 2004). The combination of F. oxysporum Schlecht. f. sp. orthoceras with BTH Benzo (1,2,3) thiadiazole-7-carbothioic acid S-methyl ester, a product that induced resistance to O. cumana in sunflower was highly effective (Müller-Stöver et al., 2005).

Application of the fungus granules into potted soil reduced the number and dry weight of Orobanche shoots by more than 90%. Orobanche shoots treated with the conidial suspension of the fungus dead by 75% in two weeks (Müller-Stöver et al., 2009).

Conidial suspension of two selected isolates of F. oxysporum significantly reduced germination, attachments, and tubercles of O. crenata. The microconidia and chlamydospores of both isolates formulated as mycoherbicides greatly reduced the number of emerged Orobanche shoots, their heights, attachments, and dry weights. Meanwhile, disease incidence and disease severity of emerged shoots were enhanced (Nemat Alla et al., 2008). Fusarium oxysporum caused heavy reactive oxygen species (ROS) damage in Orobanche induced significant irrevocable genotoxic effects on the DNA of Orobanche, degraded protein metabolism and synthesis, and finally triggered apoptosis (Aybeke, 2017a). It caused heavy hormonal disorder, triggered only SA-mediated defense, and induced intensively the accumulation of phenolic substances in Orobanche. Fusarium oxysporum causes lethal physiological damage on Orobanche spp. (Aybeke, 2017b).

Fusarium solani was reported to suppress the growth of O. ramosa in tomatoes (Gold et al., 1979). Other plant pathogens reported including, Alternaria, Fusarium, and Trichoderma were also found infesting O. crenata in Egypt (Abdel-Kader et al., 1998). Ulocladium atrum infected and destroyed underground tubercles and emerged shoots (Linke et al., 1992). Ulocladium botrytis Preuss has been also found pathogenic to O. crenata (Linke et al., 1992; Müller-Stöver and Kroschel, 2005). Myrothecium verrucaria (Alb. and Schwein.) Ditmar isolated from faba bean roots has been found to inhibit germination of O. crenata seeds and the conditioned seeds exposed to GR24 due to the production of the macrocyclic trichothecene verrucarin A (El-Kassas et al., 2005). The infection of V. faba by O. crenata could be prevented by the addition of the fungus spores to infested soil by the parasite.

Application of mycoherbicides Trichoderma harzianum and Trichoderma viride followed by foliar spray with glyphosate was the most appropriate treatment, resulting in the highest reduction in O. ramosa. Soil treatment with T. harzianum and T. viride alone or plus an aerial spray of glyphosate (50 ppm) reduced O. crenata and O. ramosa infection and increased peas, faba bean, and tomato yields (Abdel-Kader and El-Mougy, 2009). Trichoderma harzianum, T. harzianum + Rhizobium leguminosarum and R. leguminosarum reduced O. crenata incidence in faba bean by 11.5%, 8.4% and 7.6%, respectively. Trichoderma harzianum + R. leguminosarum treated plots had the highest grain yield (Aregawi, 2017).

Arbuscular mycorrhizal (AM) fungi root exudates hurt the germination of O. cumana induced by germination stimulants (Louarn et al., 2012; 2016) and a similar effect could be obtained with AM spore exudates. Production and exudation of strigolactone were significantly reduced by AM fungi symbiosis in tomatoes and the germination inducing activities of P. ramosa were significantly (p <0.01) lower in tomato plants colonized by AM fungi than in free tomato plants (Lopez-Raez et al., 2011). Mycorrhizal root exudates had negative effects on O. cumana germination (Louarn et al., 2012). Root exudates from pea plants colonized by AM fungi showed low germination inducing activities to O. crenata, O. foetida, O. minor, and P. aegyptiaca (Fernández-Aparicio et al., 2010b).

The multiple-pathogen strategy was recently developed at which two or more pathogens are used jointly and applied
before or after parasite emergence. Some of these fungi mixtures resulted in a significant reduction in theseveral emerged O. cumana shoots (Charudattan, 2001). Amsellem et al. (2001) and Cohen et al. (2002) reported a reduction in O. aegyptiaca attachment to tomato plants in glasshouse experiments using host-specific strains of F. oxysporum and F. arthrosporioides. The combination of Benzothiazole herbicide and F. oxysporum f. sp. orthoceras successfully controlled O. cumana and reduced parasite emergence up to 100% (Müller-Stöver et al., 2005).

Encapsulation of fungal propagules in a solid matrix has been already developed (Amsellem et al., 1999; Quimby et al., 1999). Pesta granules showed high efficacy in controlling O. cumana in the glasshouse (Kroschel et al., 2000; Müller-Stöver, 2001; Elzein, 2003).

Another approach is the engineering of hypervirulence genes into weed-specific pathogens which encode enzymes degrade parasite phytoalexins and enhance the production of fungal toxins (Gressel, 2002; Gressel et al., 2004).

**Chemical Methods**

**Fumigants**

Methyl bromide had been used against Orobanche in cash crops but in a limited area, under tunnels, plastic, and glasshouses for the high-cost justification. Volatile compounds such as methyl bromide, ethylene dibromide for O. crenata control in pea (Pisum sativum L.), metham-sodium for O. aegyptiaca in tomato (Jacobsohn et al., 1987), or formalin were found effective against broomrapes (Foy et al., 1989). The practice of soil fumigation has caused environmental problems (Shabana et al., 2003) and therefore, it was banned including Methyl bromide in different countries.

**Herbicides**

Below are herbicide treatments recommended for parasite control in different crops.

**Seed Treatment**

Seed treatments with imidazolinones proved effective for controlling O. crenata in faba bean. Promising results on Imazethapyr effectiveness against O. crenata through faba bean and pea seed treatments have been reported (Jurado-Exposito et al., 1996; 1997).

Coating sunflower seeds with pronamide lowered Orobanche shoot dry weight and increased sunflower yield (Sanchez et al., 2003). Soaking sunflower seeds in 0.1% boric acid or copper sulfate solutions increased plants’ resistance to herbicides and Orobanche sp. (Aziz, 1989). Seed treatment with 40 ppm benzothiadiazole, Bion for 36 hours completely prevented infection of O. cumana (Buschmann et al., 2001).

Tomato seeds immersed with chlorsulfuron (0.05-0.1% solution) or triasulfuron (0.15-0.30% solution) for 5-10 minutes caused severe phytotoxicity on emerging crops. In contrast, seed coating with lower doses (0.05-0.1 mg/kg) of chlorsulfuron, triasulfuron or sulfosulfuron was safe for the crop. Mustard seed treatment with triasulfuron, sulfosulfuron, and chlorsulfuron delayed Orobanche attachment and emergence but the effect was inconsistent at longer periods. High doses of the herbicide seed treatment resulted in poor crop seed germination and growth suppression (Punia et al., 2012).

Soaking broad beans and lentils seeds for 5 minutes in 0.01% imazethapyr solution or coating at 20-40 g/ha (at a sowing rate of 160 kg/ha) did not affect seed germination and crop growth but resulted in 60-80% O. crenata control. Imazethapyr followed by late post-emergence application of imazapyr (5g/ha) caused more than 95% weed control. Imazethapyr or with imazapyr at 5 g/ha to P. sativum seeds controlled O. crenata and seeds treated at late post-emergence resulted in excellent Orobanche control (Jurado-Exposito et al., 1996).

Effective seed treatments were found with imazapyr for broad bean and imazethapyr in lentils (Jurado-Exposito et al., 1997). However, sulfonyleurea, imazethapyr, and imidazolinone were found effective in many host crops.

**Soil and Foliar Applied Herbicides**

Soil-incorporated herbicides of dinitroanilines, sulfonyleureas, substituted ureas showing host crop
selectivity and significant soil residuality for better control of Orobanche (Parker and Riches, 1993). Sulfonylureas prevented broomrape emergence from growing on broad-leaved weeds in a non-host cereal crop. Application of metsulfuron-methyl (3 g/ha), chlorsulfuron (15 g/ha) or triasulfuron (22.5 g/ha) gave 100% control of O. ramosa with no damage to wheat or barley crops (Matthews, 2002).

Rimsulfuron selectively controlled O. aegyptiaca in tomatoes when applied through drip irrigation but the repeated application may be necessary for long-term weed control (Kleifeld et al., 1994). Three foliar applications of rimsulfuron (12.5 g/ha) followed by irrigation, at two weeks intervals after crop emergence controlled O. aegyptiaca in potato (Goldwasser et al., 2001) but gave different results in tomato because of differences in the irrigation system. The same herbicide at 10 to 20 g a.i./ha, reduced broomrape dry weight and number of shoots and was selective on tomatoes (Vouzounis and Americanos, 1998) but was toxic to eggplant. These authors reported glyphosate and sulfosate applied twice at 30 to 50 g a.i./ha were effective against O. ramosa but reduced tomato yield.

Below is the effect of chemical control of Orobanche spp. in different crops

**Broadbean (Vicia faba)**

Trifluralin applied pre-sowing and linuron post sowing gave the highest seed yield of broad bean (Vicia faba) infected with O. crenata (Zahran, 1982).

The effectiveness of glyphosate acid at 60-120g a.i./ha in controlling O. crenata in broad bean has been well documented (Nassib et al., 1984; Mesa-Garcia and Garcia-Torres, 1985; Salem et al., 1989). Ibrahim et al., (2000) reported that glyphosate resulted in high a significant reduction in Orobanche spikes ranging from 92 to 100%. This high efficiency against Orobanche increased seed yield by 3,296 and 2,550 t/ha in two locations, respectively over means of all sites (Dongola et al., 2000).

Hamid et al., (2000) reported that application of butralin (2.85 Kg a.i./ha) followed by glyphosate (58 g a.i./ha), imidazolinone (214.2 g a.i./ha), and hand hoeing (twice) reduced the fresh weight of Orobanche spikes by 95, 79, and 84%, respectively.

Imazethapyr, imazapyr, and chlorosulfuron were the most effective for O. crenata control in legumes (Garcia-Torres and Lopez-Granados, 1991), and imazethapyr against O. aegyptiacaca and O. foetida (Geipert, 1997). 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.

**Lentils (Lens esculentus)**

Glyphosate at 40 or 60 g/ha controlled Orobanche and increased lentil yield by 117 and 51%, respectively (Arjona-Berral and Garcia-Torres, 1983).

**Peas (Pisum sativum)**

Orobanche crenata cause 100% yield loss at high infestation. Two or three applications of glyphosate at 150g/ha gave the highest yield under light infestation (Jacobsohn and Kelman, 1980). Post-emergence of imazethapyr at 20 g/ha on Pisum sativum and Pisum arvense a month after planting and at 20-40 g/ha two weeks later, was effective against Orobanche and selective to pea plants (Jacobsohn et al., 1998). Ethylene dibromide alone or with chloropicrin controlled O. crenata and O. cernua (Jacobsohn et al., 1982). A pre-emergence tank mixture of propyzamide and methabenzthiazuron was effective against O. crenata (Schlingloff and Alkamper, 1992).

**Potato (Solanum tuberosum)**

Single and sequential applications of rimsulfuron between 20 and 50 g a.i./ha significantly reduced O. ramosa shoot number and dry weight. Three applications were most effective (Haidar et al., 2005b). Best results on Orobanche control and potato selectivity were obtained with rimsulfuron (12.5 g a.i./ha) followed by sequential 3 foliar application of glyphosate at 100 g a.i./ha (Haidar et al., 2005b). Orobanche aegyptiaca and O. ramosa were
controlled in potato-infested soils by split foliar applications of low rates of imazapic and rimsulfuron. Three applications of imazapic at 4.5 g/ha each, after crop emergence and re-applied at 2-week intervals, prevented Orobanche infestation (Goldwasser et al., 2001).

**Vitch (Vicia spp.)**
Nadal et al. (2008) reported that glyphosate at 35–67 g a.i./ha, applied when O. crenata attachment was at the tubercle stage of development increased seed yield of narbon bean (Vicia narbonensis).

**Cabbage (Brassica oleracea var. capitata)**
Orobanche aegyptiaca was effectively controlled with glyphosate at 60-100 g a.i./ha or imazaquin at 5-10 g a.i./ha. Trifluralin at 0.9 Kg a.i./ha may have a beneficial effect in reducing Orobanche infestation (Americanos and Vouzounis, 1995).

**Mustard (Brassica juncea)**
Glyphosate (25 g/ha) applied twice at 30 days after sowing followed by 50 g/ha at 55 days provided 65-85% control of Orobanche up to harvest without any crop injury and improved yield from 12 to 41% over the traditional farmers’ practice in different years of the study (Punia et al. 2010; Sheoran et al., 2014).

**Carrots (Daucus carota)**
Glyphosate (1-1.5 Kg/ha) resulted in moderate control of Orobanche sp. and was recommended for O. crenata and O. aegyptiaca control (Jacobsohn and Kelman, 1980).

**Celery (Apium graveolens)**
Infestation of O. ramosa and O. aegyptiaca was reduced by glyphosate (20-50g/ha). The herbicide was most effective at a high rate (Americanos, 1991).

**Parsley (Petroselinum sativum)**
Orobanche crenata and O. aegyptiaca were completely controlled with split foliar application of imazapic (2.5–5 g/ha-1) or glyphosate (36–72 g/ha-1); applied on 5–7 leaf parsley before the first cutting and on the young new growth after each cutting (Goldwasser et al., 2003).

**Oilseed rape (Brassica napus L.)**
Foliar and soil applications of Acibenzolar-S-methyl reduced O. ramosa attachment by 70% and prevented crop biomass loss (Veronesi et al., 2009).

**Sunflower (Helianthus annuus)**
Propyzamide applied to sunflower plants in the glasshouse followed by sprinkler irrigation reduced or delayed O. crenata and O. aegyptiaca infestation. Application of the herbicide with irrigation water was most effective. Direct application of glyphosate and propyzamide to the soil through an irrigation system was effective in controlling O. cernua (Kleifeld and Herzlinger, 1984).

Pre-sowing soil incorporation of propyzamide plus thiram kept sunflower free of Orobanche until the end of flowering (Herzlinger and Kleifeld, 1985). Pre-emergence application of oxyfluorfen at 1 and 2 l/ha reduced O. cumana density and further reduction was obtained with pre-sowing treatment of trifluralin at 3.5 l/ha and pre-emergence of oxyfluorfen at 1 l/ha. Oxyflourfen inhibited the formation of secondary haustorium of O. cumana (Horvath and Osztrogonac, 1991).

Imazethapyr, imazapyr, and chlorsulfuron were most effective against O. cernua and recommended for parasite control (Garcia-Torres and Lopez-Granados, 1991). Limazapyr at 10-15g/ha was effective in controlling O. cernua (Garcia-Torres et al., 1995) and pre-emergence treatment of imazethapyr was also effective (Garcia-Torres et al., 1998). In a post-emergence treatment, imazethapyr at 26.6-53.2 g/ha killed Orobanche nodules (Alonso et al., 1998).

Imazapic reduced O. cumana infestation in post-emergence and in sequential treatments in sunflower in irrigated and non irrigated fields and sunflower was not affected (Aly et al., 2001).
Tobacco (Nicotiana tabacum)

Foliage application of maleic hydrazide triethanolamine salt at 6 and 9 kg/ha completely killed Orobanche spp. and increased leaf yield and quality (Darbinyan et al., 1977). It reduced Orobanche spikes at 0.25 - 0.75 kg a.i./ha applied at 30 or 40 days after transplanting and up to the flowering stage (Dhanapal, 1996). Two applications at 1-8 l/ha resulted in 90% control of O. ramosa (Danko, 1993a) while Imazapyr and EPTC were less effective. Imazaquin at 0.07+0.1 kg, maleic hydrazide at 0.45+0.45 kg, and sulfosate at 0.2+0.3 kg all reduced number of O. ramosa plants/pot (Lolas, 1994).

Glyphosate and glyphosate trimesium (touchdown) at 100-150 ml/ha were also used to control O. ramosa in tobacco (Musselman, 1993). At 0.035% applied to the lower parts of tobacco plants in spot treatment it was effective against O. ramosa (Danko, 1993b), and under field conditions, glyphosate in 2, 3, or 4 treatments with a total dose of 1000ml/ha gave good control of O. ramosa (Sandri et al., 1998). At 0.5 kg a.i./ha applied at 60 days after transplanting and imazaquin at 0.01 kg a.i./ha at 30 days after transplanting reduced Orobanche population by almost 80% and increased tobacco leaf dry weight by more than 40% (Dhanapal et al., 1998).

Tobacco gave a similar yield to weed-free treatment when 1.5 kg fluchloralin, 0.75 kg bentiocarb, or 0.1 kg oxyfluorfen, and 4-inter-raw cultivation were done (Metha et al., 1985). Pre-plant application of fluchloralin at 2 kg/ha gave a high tobacco yield equal to the weed-free treatment. Fluchloralin and 4 kg diphenamid/ha were highly selective to tobacco while peptulate and fluchloralin each at 3 kg/ha were highly effective against O. cernua (Palled et al., 1985).

Allyl alcohol at 0.1-0.2 concentration sprayed 4 times at weekly intervals reduced Orobanche infestation (India, Central Tobacco Research Institute, 1979). Chlorsulfuron (2g/ha), imazaquin (70 and 100g/ha), and imazapyr (20-30 g/ha) were applied pre-transplanting, and glyphosate (200-300g/ha), glyphosate-trimesium (300 and 400 g/ha), imazaquin (70 and 100 g/ha) and maleic hydrazide (450 g/ha) applied over tobacco plants were effective in controlling Orobanche with no phytotoxicity in oriental cultivar (Lolas, 1997).

Tomato (Lycopersicon esculentum)

Glyphosate and sulfosate applied twice at 30 to 50 g a.i./ha were effective against O. ramosa and O. aegyptiaca on tomato and eggplant but reduced tomato yield. Variations between tomato cultivars were detected for glyphosate treatment at 150 ppm. glyphosate in 250l water /ha applied at 2-true leaf stage (Foy et al., 1988).

Three applications (at bud formation, near flowering, and beginning of ovary formation) of glyphosate at 150 g/ha resulted in the highest tomato yield and lowest O. ramosa number (V’lchev et al., 1995). Metham-sodium in drip-chemigation controlled O. aegyptiaca at 20-100 l/ha (Kleifeld et al., 1991). Polyethylene mulching of the metham treated soil drastically improved metham performance and O. aegyptiaca control.

In pot experiments, chlorsulfuron applied at 37 and 180 g a.i./ha was the most effective for O. ramosa control and least toxic to tomato (Syka and Eleftherohorinos, 1991). Orobanche aegyptiaca control in tomato was achieved with the 3-split application of chlorsulfuron at 2.5 g a.i./ha and triasulfuron at 7.5 g a.i./ha (Hershenhorn et al., 1998). Qasem (1998) reported excellent control of O. ramosa using chlorsulfuron at 2.44 g a.i./ha in irrigation water or directly incorporated into the soil.

Bensulfuron, chlorsulfuron, nicosulfuron, primisulfuron, trimsulfuron, thifensulfuron, and triasulfuron were tested for their effects on seed germination of O. aegyptiaca at preconditioning and germination stages. All herbicides reduced radical elongation of the parasite. Chlorsulfuron and triasulfuron applied to 2.5 and 25 μM a.i. and rinsulfuron at 5μM a.i. at preconditioning and germination in vitro almost completely inhibited parasite development (Hershenhorn et al., 1998). Single application of rinsulfuron (25 g a.i./ha) to tomato at 10 days after planting and split applications at 10 and 20, 20 and 30 days after planting significantly reduced number of O. aegyptiaca inflorescences.
Chlorsulfuron and triasulfuron applied directly to soil at rates ≥ 3.75 g a.i./ha completely controlled O. aegyptiaca. Rimsulfuron at 10 to 20 g a.i./ha reduced Orobanche weight and number of shoots (Vouzounis and Americanos, 1998). Primisulfuron and chlorimuron each at 22.5 g a.i./ha reduced the number of parasite inflorescence (Hershenhorn et al., 1998).

Three split applications of 2.5 g/ha chlorsulfuron through sprinkler irrigation, starting two weeks after transplanting and at 10-14 days intervals followed each application by 300 m3/ha irrigation, controlled 80-90% of Orobanche with no phytotoxic effect on tomato (Hershenhorn et al., 1998). Chlorsulfuron, effectively controlled Orobanche’s late emergence around drip emitters in tomatoes (Kleifeld et al., 1999), but results were inconsistent in other tests. Chlorsulfuron at 2.38g, 7.14g, and 11.9 g/ha gave 63.45%, 100%, and 81.81% parasite control, respectively (Dongola et al., 2000).

Sulfosulfuron was highly effective and selective for O. aegyptiaca control (Eizenberg et al., 2001) but chlorsulfuron and triasulfuron were most effective through chemigation. The herbicide acts mainly through the soil. Successful chemical control of O. aegyptiaca in processing tomato was achieved with sulfosulfuron and imazapic (Parker, 2009). Two (14 and 42 days after planting) or three (14, 28, 42 days after planting) foliar applications of 50 g ha-1 monitor effectively controlled O. aegyptiaca in tomatoes. These Effective control of Orobanche in tomatoes grown under irrigation was achieved by pre-emergence application of sulfosulfuron at 75 g/ha (Dinesha et al., 2012).

Deep incorporation of dazomet at 3 weeks before transplanting tomato prevented or delayed Orobanche emergence. Dazomet, which releases the toxic gas methyl isothiocyanate to control Phelipanche mutelii, was confirmed under field conditions in Australia (Prider and Williams, 2014).

Imazethapyr 20, 40 and 80 g/ha resulted in 77.72%, 72.7% and 78% control, respectively. Oxadiazon controlled Orobanche spp. when applied in sprinkler irrigation to the root zone of tomato (Kleifeld et al., 1982). Imazaquin and glyphosate applied at 37 and 180 g a.i./ha, respectively, controlled Orobanche but imazaquin reduced crop yield (Syka and Eleftherohorinos, 1991).

Trials for chemical control of O. ramosa in tomatoes showed that imazethapyr and chlorsulfuron were effective for both crop/parasite situations (Dongola et al., 2000). Application of the imidazolinone systemic herbicide Cadre (Imazapic ammonium salt) on tomato foliage prevents fruit setting by damaging the reproductive system. Tomato flowers throughout the growing season, with fruit set peaking at 50 to 60 days after planting. However, early treatments with monitor followed by Cadre application after the fruit setting peak completely controlled O. aegyptiaca in tomatoes without causing any damage to the yield (Lande et al., 2005). Application of imazapic and imazapyr during tomato cultivation using an IR tomato mutant demonstrated high P. aegyptiaca control efficacy (Dor et al., 2016). A foliar application of maleic hydrazide to tomato reduced P. aegyptiaca attachment on the host roots without any influence on tomato foliage or root dry weight (Samejima and Sugimoto, 2018).

**Advanced Biotechnology**

These include the use of nanotechnology (P´erez-de-Luque and Rubiales, 2009), genetic engineering that enables the use of herbicides including the non-selective chemical on crop plants and targeted weed species providing that the herbicide-resistant gene is transferred into crop plants (Qasem, 2013). Transgenic allelopathic crops that could prevent parasite seed germination, reduce or delay the release of parasite seed germination stimulant, or prevent attachment of the parasite or haustorial development and Gene Silencing technology effectively through a segment of a double-stranded RNA (dsRNA) inserted in host plants and can move into the parasite and inhibit parasite target gene leading to its impaired expression (Fire et al., 1998; Dubey et al. 2017), preventing its function and reducing parasitism.
Integrated Control Methods

Not all satisfactory measures of control have been found so far, therefore a combination of suitable measures for a specific situation in the sense of an integrated approach seems to be the most appropriate way to deal with the problem. The results obtained from any single control method were insufficient. Combining two or more methods is necessary to easier deal with the problem. In this regard analysis of the farming system looks important http://www.uni-hohenheim.de/~www380/parasite/oro_path.htm).

The only effective way to counteract parasitic weeds problems is to apply an integrated approach (Rubiales and Fernández-Aparicio, 2012) through a combination of all possible weed control methods and tools. These include preventive, cultural; mechanical; Physical; biological; and future research and biotechnologies and chemical methods

It is to conclude, that until now developments in control strategies are not advancing beyond agronomic practices, resistant varieties, and possible chemical control by herbicides. Therefore, integrated methods through varying agronomic measures are always recommended for some acceptable level of parasite control and to avoid total yield loss under heavy infestation. Taking into consideration the cost, persistence, low selectivity and negative environmental impacts of some recently reported effective sulfonylurea and imidazolinones herbicides against certain parasite species, alternatives, and eco-friendly methods are necessary. These may be recently thought through the use of safe natural products, plant materials, and their byproducts, allelopathy, resistant varieties, trap and catch species in rotation with host crops, botanical herbicides, growth promoters, and fertilizers, mechanical and physical methods including plastic mulch and soil solarization and even eating broomrape might be all considered as part of the integrated control package. All are strongly recommended for parasites and other weeds control in general.

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أنواع الهالوك (Orobanche spp.)

التحدي والإدارة: مراجعة

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الملخص

تعد أنواع الهالوك (الأوربانشي) من الأعشاب الطفيلية الأكثر تدميراً وضرراً للزراعة، وتتوضّع هذه الطفيليات على جذور العيد من الأنواع النباتية المزروعة والبرية التي تتضمن تحت عائلات نباتية عديدة، وتختلف هذه الأنواع الطفيلية في الشكل الظاهري والعوامل النباتية التي تهاجمها على الرغم من أنها تنتشر في عدد كبير من أنواع العوائل المختلفة، وتظهر أنواع معينة من الهالوك أكثر تخصصاً من غيرها في تطفلها على عوائل ذات طبيعة نمو معينة كالإنزجار المزهرة والحجمية، وكل أنواع الهالوك هي أنواع إدارية تتطور تطور إلى صبغة البخصور (الكلوروفيل) وهي تعبع ذلك عبارة عن فعالة تعود بشكل كامل على عوائلها النباتية في تحمل على النبات كمصدرين للمياه والغذاء، وتعتبر هذه الفاعلية من أهمية اقتصادية، وطرق الإدارة للأنواع واسعة الانتشار والأكثر أهمية من الهالوك في الأردن والأعمال التي تسببت في خسائر فادحة في إنتاج الكثير من المحاصيل الاقتصادية المهمة، وقضايا من الإنتاج بشكل كامل في الأصوات الكثرية، تم تضمن ومناقشة أحدث ما وصل إليه الباحثين من طرق المكافحة المتاحة حالياً في الأردن وفي مناطق مختلفة من العالم.

الكلمات الدالة: الأعشاب الطفيلية، أنواع الهالوك (الأوربانشي)، العوائل النباتية، الإدارات.