Egypt. J. Chem. **Vol. 65**, No. 4, pp. 53 – 65 (2022)

Egyptian Journal of Chemistry

http://ejchem.journals.ekb.eg/

Safe methods as alternative approaches tochemical herbicides for controlling parasitic weeds associated with nutritional crops: a review

Mahmoud A. T. El-Dabaa[1*], Ghada A. Abo-Elwafa[2] and Hassan Abd-El-Khair[3]

[1]Botany Department, Weed Biology and Control; [2] Fats and Oils Department and [3]Plant Pathology Department, National Research Centre, 33 El Bohouth St., Dokki, P.O. Box 12622, Cairo, Egypt

Abstract

Weeds are among the important pests of agricultural and nutritional crops causing major yield loss, ranged between 10% to 98% of total crop yield, which may vary from crop to other or region to other in the same crop. This loss in crop yield results when parasitic weeds attach themselves to another plant, their 'host', and draw nutrients from it causing huge damage to the host crop and consequently huge economic loss. *Orobanche* spp., *Striga* spp. and *Cuscuta* spp. are the most common parasitic agricultural weeds with economic importance in many world parts. Applying control methods selective enough for killing these parasitic weeds without causing crop damage is as difficult as the application of chemical herbicides which causing soil and water contamination and adverse effects to beneficial organisms and hence loss in the nutritional benefits of the cultivated crop. In some cases chemical compounds which resulting from herbicide degradation process may continue to be significantly toxic to health and environment. A review was made to highlight research conducted yet concerning important alternative methods to herbicides, such as biological control; natural products; agricultural practices and cropping systems, for controlling parasitic weeds and their management in nutritional crops.

***Key words*:** Agriculture practices, biological control, cropping systems, nutritional crops, parasitic weeds, natural herbicides, management options.

1. Introduction

The problem of parasitic weeds is considered a major challenge facing agricultural economy, besides other important agricultural pests, causing major yield loss ranged from 10% to 98% of total crop especially nutritional crops. These yield losses caused by weeds may vary from crop to other or region to other in the same crop, according to some factors including weed capacity, availability of weed control technology and weed control expenses [1]. Parasitic weeds exploit another vascular system of host plants to obtain their nutrients requirement and hence cause lack of nutrients and then damage to the host plants. The families *Orobanchaceae* (*e.g.* *Orobanche*), *Scrophulariaceae* (*e.g.* *Striga*) and *Cuscutaceae* (*e.g*. *Cuscuta* spp.) are common parasitic agricultural weeds with economic importance in many parts of the world [2]. *Orobanche* spp. may distribute over the worldwide through temperate climates to the semi-arid tropics. *O. crenata* is spread in Mediterranean region and Middle East & East of Africa, while other *Orobanche* spp. weeds have a wider spread. Today, *Orobanche* species such as *O. aegyptiaca* , *O. cernua* , *O. crenata*, *O. cumana* , *O. foetida* , *O. minor* and *O. ramosa* are the major biotic limiting factors to legumes production (Chickpea , faba bean and lentil), *Solanaceae* crops (Potato , tobacco and tomato) and *Asteraceae* (Sunflower). *Orobanche* spp. could cause 33% yield loss in tobacco, 50–100% in beans, 33% in sunflower, 24% in carrots and 29 % in

*Corresponding author e-mail: eldabaam@yahoo.com
Receive Date: 30 September 2021, Revise Date: 13 October 2021, Accept Date: 19 October 2021
DOI: 10.21608/EJCHEM.2021.98930.4602

tomatoes [3,4]. Parasitic *Striga* weeds, such as *S. hermonthica*, *S. asiatica* and *S. gesnerioides*, are the common economic important weeds in the semi-arid to sub-humid tropics. *S. hermonthica* is widespreaded in the semi-arid zones of Northern Tropical Africa. *Striga asiatica* has a wide distribution in the eastern to southern parts of Africa, Asia, Australia and the United States and *Striga gesnerioides* occurred in Africa. *Striga hermonthica* and *Striga asiatica* species are almost entirely specific to cereals *e.g.* sorghum, maize, pearl millet, rice, sugar cane and others. *S. gesnerioides* is parasitizing dicot hosts, mainly cowpea, tobacco and sweet potato [5]. Field dodder (*Cuscuta* spp.) is an annual obligate parasite includes about 175 species spreading worldwide. It causes serious problems to alfalfa, clovers, chickpea, lentil , pea, linseed , greengram , pigeonpea , sesame , soybean , tomato , potato , carrot , sugar beet , cranberry , blueberry , citrus and ornamental species. *Cuscuta* may decrease the yield in chillies by 60-65%, greengram (31-34%), niger (60-65%), in lentil (87%), chickpea (86%), tomato (50-75%) and alfalfa (60- 70%) depending on infestation intensity [6,7].

Controlling parasitic weeds is challenging because it is difficult to fight weeds by applying control methods selective enough for killing it without causing crop damage. Controlling parasitic weeds may also be hindered by its high fecundity, dispersal efficiency, persistent seeds bank or rapid response to agricultural practices [8]. Also, chemical herbicides, which are used for controlling these parasitic weeds, can remain active in the environment for long periods of time causing soil and water contamination and adverse effects to beneficial soil organisms. In some cases, compounds resulting from herbicides degradation process may continue to be significantly toxic to health and environment. Therefore, application of methods alternative to chemical herbicides in weeds management systems may be the best way to find environment friendly, effective, long-lasting and widely applicable methods. The ideal target of successful controlling of parasitic weeds should be supported by limiting the life cycle of weed, prevention of seeds germination and/or host binding. Without management, seed banks of the parasitic weeds existing in the soil will increase rapidly and hence, it can widely distribute to other lands leading to new infestations. So, long-term combating strategies are essential to overcome these harmful weeds. A set of measures must be included in these strategies in order to reduce containment and to prevent the build-up of seed banks. These measures include the use of non contaminated soil, seeds and transplants of the crop, grazing animals and equipments beside reducing the production of the parasite seeds in the infested fields by applying natural approaches like hand weeding, using resistant and tolerant crops, catch and trap crops, soil fumigation, soil solarisation and flooding [9]. Recently, some fungal metabolites were affected *Striga* spp. and *Orobanche* spp., where these strategies may be an alternative mean as biological control of parasitic weeds [8]. This review will describe the up-to-date knowledge on how to control parasitic weeds through different natural strategies alternative to chemical herbicides.

2. Biological control

Biological control of weeds can be obtained through using natural antagonists for reducing its level below economic importance. Soil microorganisms and insects can have a number of advantages in controlling parasitic weeds through attacking its seeds in the early stages of development and hence make it less sensitive to the environmental conditions and then reducing its survival in the soil [10, 11]. It can also be integrated with other cultural practices such as crop rotation. Biological agents attack seeds and then reducing its stored number in the soil or release toxins causing stunt root growth. Therefore, biological control may play an important role in suppressing parasitic weeds due to physiological relationships with its hosts [12]. Bio-control agents can reduce seeds bank of *Orobanche*, *Striga* and *Cuscuta*, which attack legumes, cereals and vegetables, in early developmental stages [10]. Applying bio-agents had strategy for wide host ranges and enhancement of suppressive activity of weeds in conventional or sustainable agricultural systems [13]. Using microorganisms such as *Fusarium* spp. and symbiotic bacteria such as *Rhizobium* spp. successfully controlled *Orobanche* spp. The mechanisms of microorganisms for controlling *Orobanche* spp. have two ways: one is to secrete metabolites that directly inhibiting seeds germination or growth of broomarpe or indirectly affect the parasitic behavior and growth of *Orobanche* spp. by enhancing host plant resistance against *Orobanche* spp. [14].

2.1. Fungal biocontrol agents:

2.1.1. *Fusarium* spp.:

Parasitic weeds are suitable targets for bio-herbicidal agents, where 30 fungal genera were isolated from *Orobanche* species [15], while about 16 fungal genera were recorded on *Striga* spp. [16, 17]. *Fusarium* spp. are the most prominent fungi associated with the infected *Orobanche* ssp. or *Striga* spp. and *Cuscuta* spp. according to survey results. *Fusarium* spp. has many advantages in fighting weeds and to be suitable in bio-herbicide approaches, where *Fusarium* spp. when added to soil could improve the crop yield by destroying parasitic weeds at early developmental stages. For example, *F. arthrosporioides*, *F. nygamai*, *F. oxysporum*, *F. oxysporum* f.sp. *orthoceras*, *F. semitectum* var. *majus*, *F. solani* significantly showed disease symptoms on *Orobanche* [18, 19] and *Striga* [17, 20] even if no host plant for the parasite occur in the field.

Therefore, *F. oxysporum* f.sp. *orthoceras* recorded the excellent control against *O. cumana* on sunflower under greenhouse conditions by reducing 80% of the total number of *O. cumana*. Using host-specific strains of *F. oxysporum* and *F. arthrosporioides* also could reduce *O. aegyptiaca* on tomato under greenhouse experiments [21]. During extensive surveys in heavily fields infested by *O. ramosa* in Southern Italy, a large number of fungi were isolated from infected parasitic plants. More than 50 isolates belonging to 15 different species were selected to assess their pathogenicity and virulence against broomrape. Some of the tested isolates that quickly caused necrosis and rotted the attached tubercles were further tested in pot trials in a greenhouse. Among them, an isolate of *F. oxysporum* and *F. solani* were promising, where they strongly caused 60% reduction in the number and weight of the emerging shoots of broomrape, and by > 70% in the number of tubercles attached to the host roots by. Isolates of *F. camptoceras* and *F. chlamydosporum* caused around 50% control of broomrape [15]. *F. solani* and *F. oxysporum* significantly increased the dead spikes of broomrape in tomato plants [22]. *F. verticillioides*, isolated from *O. cumana* tubercles, was highly pathogenic to *O. aegyptiaca*, *O. ramosa* and *O. cumana* in the polyethylene bags. In pots, the fungus caused wilting and necrotic areas on flowering shoots of *O. cumana*, but did not cause disease symptoms on *O. crenata*. The toxic metabolites were isolated and identified by spectroscopic methods as fusaric acid [23].

Soil microorganisms can also be used as a safe, environmentally friendly and cost effective tool to control S*triga*. *F. oxysporum* f.sp. *strigae* could control *Striga* in field trial, when applied with susceptible and resistant varieties of sorghum and maize [24]. Zahran [25] showed that 28 fungi were associated with *S. hermonthica* in Sudan, among of them *F. nygamai* and *F. semitectum* var. *majus* were applied for controlling *Striga*. Two mechanisms were identified by *F. oxysporum* f.sp. *strigae* for controlling *S. hermonthica*. (i) Complete digestion of weed seedlings inside the host and (ii) clogging of vessels of emerged weed by hyphae contributing to wilting and subsequent death [26]. Glasshouse trials were performed to investigate the control of *S. hermonthica*, by *F. nygamai* at different inoculum substrates and inoculum amounts, using the host plant sorghum (*Sorghum bicolor*). *Striga* incidence was decreased up to 100% when the fungus was incorporated into the soil pre-planting, whereas emerged *Striga* at different stages of growth up to the flowering stage were killed by applying the fungus at post emergent. Strains of *F. nygamai* and *F. oxysporum* found to reduce *S. hermonthica* emergence by 90% or more [27]. The presence of *F. oxysporum* (PSM 197) significantly reduced the total number of emerged plants of *S. asiatica* (91.3%), *S. gesneroides* (81.8%) and *S. hermonthica* (94.3%). This high susceptibility of the three *Striga* species provides a possible opportunity to control these parasites simultaneously with this mycoherbicide [28]. *F. oxysporum* f.sp. *strigae* reduced the incidence of *Striga hermonthica* infestation under experimental conditions, where it sufficiently effective in reducing the soil *Striga* seed bank [29].

Inoculums obtained from the spores of *F. tricinctum*, a species of *Alternaria* and their mutations could control the growth of dodder (*Cuscuta* spp.) on field crops. A pathogenic fungus, *Colleotrichum gloeosporioides*, also isolated from dodder in soybeans, could control dodder in the field applications [30]. *Fusarium* spp., *Alternaria* sp. and *Colletotrichum* sp., isolated from infected tissues of dodder, were inoculated with concentration of 1×10^{8} spores per ml sterile water at different growth stages of dodder in laboratory and greenhouse. Among these different fungi, *F. oxysporum* isolate showed an effective control on dodder seeds germination and the highest level of dodder infection before its contact of with the host. This isolate infection showed no symptoms with crops such as sugar beet, alfalfa , basil ,wheat , and barley [31].

2.1.2. *Trichoderma* spp.

Trichoderma is a beneficial fungus that can be widely applied as a biological agent to control many plant pathogens, such as bacteria, fungi, viruses, nematodes and higher parasitic plants. It attacks and suppresses the growth of the pathogens exist in soil and hence improves plant growth. Chitinase, proteases and β-1,3-glucanase are some of the enzymes that are produced by *Trichoderma*. These enzymes induce plant defence and resistance as well as active and strong competition for nutrient against plant pathogens. Therefore, *Trichoderma* proved to be an important biological control agent in sustainable agriculture to reduce plant diseases and to increase field production [32]. *Chaetomium* sp., *F. oxysoprum, F. solani, Rizoctonia solani, Sclerotium rolfsii* and *harzianum* could attack *O. ramose* living tissue segments causing black lesion and soften rot with completely deterioration within 7 days in *in vitro* tests. Application of *T. Harzianum*, *T. viride* and *T. hamatum* reduced *orobanche* shoots number, in comparison with control [33]. *T. harzianum*, *T. viride* and *T. Vierns* were applied in comparison to glyphosate for controlling *O. crenata* in faba bean. All tested *Trichoderma* spp. were capable to control *O. crenata* causing better juvenile number reduction, than glyphosate [34]. *Trichoderma hamatum*, *T. viride* and *T. harzianum* were applied for controlling *O. ramose* in chamomile plant, we found that soil contaminated with *Trichoderma* spp. was effective in reducing infection with *O. ramose* by delaying in *Orobanche* attachments and reducing number and growth of tubercles [35]. *T. hamatum* and *T. viride* completely protected chamomile plants against *Orobanche* infestation until 3 months after transplanting.

Hassan *et al*. [36] tested the different efficacy parameters of the fungus *T. harzianum* as culture age, inoculum type, application time and fungal extract, for controlling the germination of *S. hermonthica* infestating sorghum. The significant inhibition of *S. hermonthica* germination was obtained after 10 days by *T. harzianum* culture. Applying all concentrations of the aqueous and ethyl acetate extracts of *T. harzianum* significantly reduced the germination of *S. hermonthica* seeds. All types of *T. harzianum* inoculums in all inoculation types (Autoclaved, culture and filtrate) significantly ($P \leq 0.05$) reduced the germination of *S. hermonthica* seeds. Moreover, The combinations of compost with *T. harzianum* and with BMP+ *Flavobacterium* significantly reduced *S. hermonthica* dry weight, increased sorghum shoot and root dry weight insignificantly [36]. The management of *Cuscuta campestris* parasite was found to be very difficult due to many factors like; their complicated relationship with the host, wide host range and lack of resistant genes in the host. To control this parasite in chickpea, Kannan *et al*., [37] used native isolates of *Trichoderma viride* and *Pseudomonas fluorescens* as seed treatments and foliar spray to induce systemic resistance on chickpea against *Cuscuta campestris* parasite. It was compared with salicylic acid and thiobenzamidazole (synthetic elicitors) which were used as standard inducing agents. Applying these bio-agents induced high production of defence enzymes in chickpea and thus delayed *C. campestris* development and flowering.

2.2. Insects

Insects can be classified according to the site it damage into defoliators (*e.g. Junonia* spp.), gall forming (*e.g. Smicronyx* spp.), shoot borers (*e.g. Apanteles* spp.), miners (*e.g. Ophiomyia Strigalis*), inflorescence feeders (e.g. *Stenoptilode staprobanes*) and fruit feeders (*e.g. Eulocastra* spp.) [38]. Insects can play role in controlling parasitic weeds, but those that were recorded on *Orobanche* spp. or *Striga* spp. were limited. *Phytomyza orobanchia* can attack *Orobanche* species only as specific host, while *Smicronyx* spp. (a gall-forming weevil) is specialised on *Striga* spp. These insects could prevent the production of weed seeds through the development of larvae inside the seed capsules of the parasite and hence reduce its capacity to reproductive or spread (figure 1), but deep ploughing is a factor that limited the effect of *P. orobanchia* or *Smicronyx* spp. in soil cultivation. On the other hand due to its short life time or enormous seeds production and host damage caused by un-emerged plants, both *Orobanche* and *Striga* cannot be regarded as ideal target for biological control by these insects.

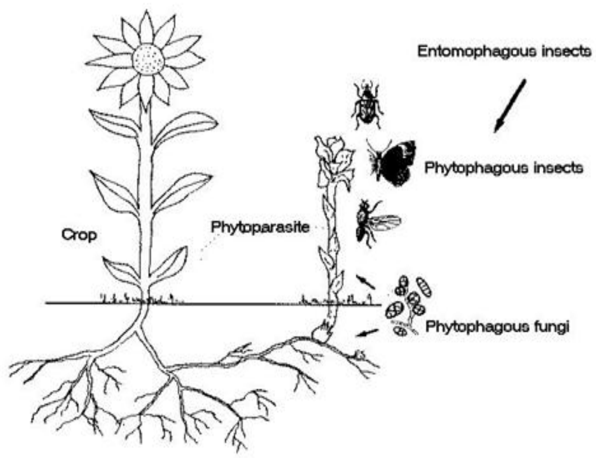

Figure (1): Insects as biological agent controlling parasitic weeds

3. Natural products' herbicides

Recently, application of natural products' herbicides received a considerable attention as alternative to chemical-herbicides for controlling weeds over the world. Natural herbicides can be obtained from plants or microorganisms as safe, bio-degradable and selective useful for environment and could provide an alternative tool for combating parasitic weeds [39]. Natural products such as plant extracts, essential oils or allelo-chemicals gained attention because of its short half life and low toxicity to the environment. The commercial available natural herbicides mostly are non-selective and require careful application to preserve cash crops. Many studies in this field mentioned that using natural products is still not common because of its difficult cost due to its complex structure synthesis, poor performance as well as its rapid degradation. Also, it was reported that when natural herbicides were singly applied they not perform, but in integrated approaches it could provide best results. Natural herbicides can be bio-degradable that do not leave residues in the soil, but they are not specifically targeting the weeds, where there is ability to affect other non-target species as well [40]. The allelopathic effect of *Dendrophthoe falcata* plant was studied on germinations of paddy and green-gram seeds. The extracts of *D. falcata* had significantly positive inhibitory effect on germination and growth of paddy and green-gram seeds varied through its concentrations. The allelopathic potentiality of plants could positively help for inducing purification of allelopathic substances which have bio-activities [41].

The allelopathic effects of seeds powder of *Sinapis alba* (Sasp) was studied on the growth and yield of two *Vicia faba* cultivars under *O. crenata* infection in pots, in comparison to the herbicidal effect of Basamid. All Sasp concentrations minimized the dry weight of *O. crenata* tubercles/pot at 90 days of sowing or at harvest time. The Sasp concentration at 45g/kg soil and Basamid (0.4g/pot) gave the best results for controlling *O. crenata* infection in two faba bean cultivars. It is clear that the presence of allelochemicals, mainly glucosinolates and phenolic contents, may be played role as a natural bio-herbicide for controlling *O. Crenata* [41]. Also, El-Dabaa *et al*., [42] studied the allelopathic effect of seeds powder of *Eruca sativa* (Essp) in comparison to the Basamid herbicide for controlling *O.crenata* in faba bean. The concentrations of all Essp as well as Basamid minimized the numbers and the fresh & dry weight of *O. crenata* tubercles. Both Essp (45 g/kg soil) and Basamid (0.4 g/pot) revealed the best effective for controlling *O. crenata* in two faba bean cultivars. In the same manner, seeds powder of Essp or Sasp had inhibitory effects against *O. ramosa* in tomatoes where the highest yield of tomato was obtained by applying both Essp and Sasp at dose 45 g/kg and 30 g/kg, respectively [43]. A bioassay experiment was employed to study the inhibition effect of fenugreek, fennel and radish on seed germination of *O. crenata* in presence of the two faba bean cultivars (Misr 3 and Giza 843), fenugreek inhibited seed germination of broomrape on both cultivars. Whereas, radish significantly inhibited parasite seeds germination in Misr 3 only, but fennel showed no effect on parasite seed germination. Moreover, the results of this study indicated that under field conditions intercropping with fenugreek produced the lowest number of emerged spike [44]. Abd El-Ghany et al [45] studied the allelopathic effect of *Eruca sativa* (Essp) and *Sinapis alba* (Sasp) seed powder in controlling O. crenata infesting Pisum sativum. They found that adding seed powder at the rate 12.5 and 25 g/kg soil of both Essp and Sasp was the optimum applied treatments that suppressed O. crenata weed with the highest yield of P. sativum as compared with the healthy control.

4. Agricultural practices:

Prevention is the most effective method for dealing with weeds entered the field. Preventive measures can be applied at different times or in parallel where their effectiveness or importance in controlling weeds depends on the weed species and environmental climatic conditions. Some management methods were highly effective for different weed varieties during their different growth times and therefore it can be used throughout the life time of the crop. The following are some agricultural practices that can be applied as preventive measures to control parasitic weeds.

4.1. Crop rotation

Crop rotation is the oldest effective agricultural control measure to regulate weeds presence by application of the nitrogen-fixing leguminous crops. It helps to avoid the build-up of weed seeds bank as well as it could improve fertility or soil structure by alternation of dipping or shallow plant roots. Crop rotation can play an important role in promoting weeds suppression, water and soil quality, cycling efficiency of nutrients and maintaining good productivity of yields. The rotation can begin firstly with legumes or *Brassica* species which leave beneficial nutrients for the following crops. Legumes could fix nitrogen and hence producing high quality soil and then enhance the habitat of beneficial insects. The *Brassica* species, by producing glucosinolate-containing residues, could suppress the soil borne pathogens [46]. Egyptian clover, Flax or fenugreek were found to be a successful trap crops for *O. crenata* in rotation with rice and due to water flooding they reduced the infestation. Schnell *et al*., [47] mentioned that incorporating resistant legumes in crop rotations reduced broomrape to low level.

4.2. Hand weeding, transplanting and deep sowing

Hand weeding is the most common method for controlling parasitic weeds, where it is the only present way for controlling *Rhamphicarpa fistulosa* in their lowland rice fields. Weeding of *Rhamphicarpa* is effective to prevent damage to the host plant as well as avoiding production or dispersal of weed seeds. Weeding of emerging or flowering obligate parasites such as *Striga*, *Phelipanche* or *Orobanche* is conducted after spotting the appearance of the parasites above ground only. Removing weeds by hands is an important tool for reducing future infestations, if it is applied before seeds production or release. The weeded plants should be destroyed effectively outside the field to avoid seeds ripen when the plants are disconnected from the host. Also, hand weeding was found to be useful to avoid the spread or increase of the *Orobanche* seeds bank in the field, where this technique is mostly available only in some developed areas [48, 49]. Transplanting could reduce parasitic weeds infestation and gives the crop time advantages to more competitive with parasitic weeds such as *Striga*. Transplanting is used for production of rice in lowland to avoid weeds competition and to enhance weeding operations. Rodenburg *et al*., [50] reported that transplanting was as a successful measure in cultivating rice in lowland fields infested by *R. Fistulosa*. It also proved to be an effective method for reducing *Striga* infestation in sorghum, comparing with seeds sown sorghum [51]. Deep sowing may contribute for parasitism reducing, as when the standard sowing depths at 2.5 cm, in sorghum and maize, under high levels of *Striga* infestation, seeds bank were 1,397 and 1,876 seeds/dm^3 respectively. While, when deep sowing was at 15–20 cm, in cone-shaped holes, the seed bank of *Striga* reduced by 55% and reached 836 and 970 seeds/dm3 under moderate infestation level [52].

4.3. Mulching and soil solarisation:

Mulch systems are useful for suppressing weeds by blocking or reducing solar radiation and increasing temperature ranges on the soil surface and hence preventing weed seedlings growing. Plant wastes or synthetic mulches can be used for covering or mulching the soil as one of the most used management practices for reducing weeds problems by preventing seeds germination of weeds or suppressing the growth of its emerging seedlings. Straw, sawdust, weeds, paper and plant residues can be used as natural mulches.

Soil solarisation or solar heating is formed by trapping the soil with a transparent polyethylene sheet during the hot season, before crop planting. Soil solarisation is successfully used in many countries for controlling or reducing soil pests like weeds and others. As shown in Fig. (2), polyethylene sheets collect radiant heat from the sun and consequently, the soil is heated and hence controlling the target pests [53]. This technique was found to be useful in controlling seeds bank of broomrape by covering the upper soil level for 5–6 weeks, where the soil temperature reaches 50ºC or higher within the day. The lethal high temperatures cannot reach below the upper soil layer by 15–20 cm in heavy clay soils and then broomrape seeds could be allowed to escape, but only for carrot, which develop shallow root systems in heavy clay soil, solarisation is sufficient,. About 100 % loss of seeds germination of *P. aegyptiaca* obtained by heat treatment at 55ºC, under laboratory conditions. Also, solarisation was an effective controlling strategy for *Striga* spp. and *R. fistulosa*, in the farming systems of sub-Saharan Africa on large scale [54, 55]. In the same manner, covering the moist soil with a layer of polyethylene could efficiently control broomrapes in faba bean under high-temperature conditions [56].

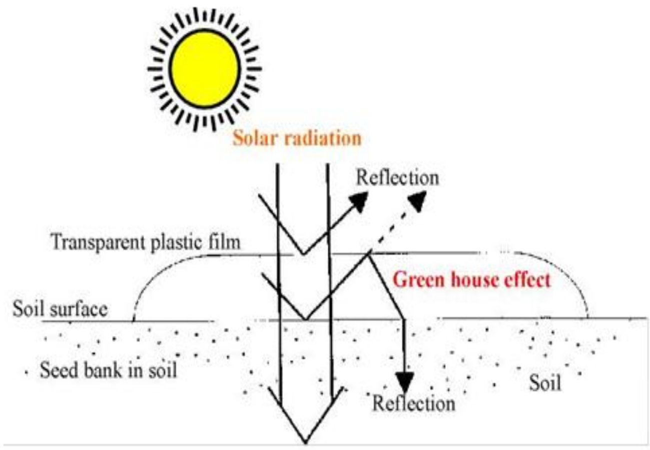

Figure (2): Mechanism of solarisation as a controlling method of parasitic weeds

4.4. Irrigation or flooding

Flooding can control broomrape by decaying the seeds of the parasitic weed and hence decrease the infestation in fields. Flooding for long periods of time could significantly reduce the infestation of *O. crenata* in host plants, but shorter flooding periods were not effective. In laboratory study, *P. aegyptiaca* seeds in containers of flooded soil for 9 days completely prevented seed germination. Continuous flooding technique was found to be an effective method for controlling parasites in lowland rice fields. It also could control *Striga* spp. as well, where a part of rice, which is susceptible to be attacked by *Striga*, could grow under flooded conditions [50]

4.5. Enhancing soil chemical fertility

Soil fertility plays key role in the management of *Striga* and *Rhamphicarpa*, where the deficiency in phosphate and nitrogen enhances the biosynthesis of strigolactones which stimulate parasites germination. Jamil *et al*., [57] reported that when the levels of N and P in the soil increase through the implementation of fertilizers, the germination and rates of infestation of the parasitic weeds reduced. Fertilizers application reduced the *Rhamphicarpa* population according to Rodenburg and Bastiaans, [58]. When Riches *et al*., [59] applied urea to enhance soil fertility, within 3 weeks of sowing, the numbers of emerged *S. asiatica* plants were reduced in rice fields. Parker, [60] concluded that poor soil fertility is the main factor leading to high *Striga* infestation, so increasing organic matter in the soil decreased *Striga* infestation, where soil content of organic matter seemed to be the most important factor to preserve soil fertility. Reduction in of *S. hermonthica* number and weight was recorded due to N application using urea. Similarly, Kamara *et al*., [61] showed that a reduction in *Striga* infestation and damage was reduced by N fertilizer application in maize. Dzomeku and Murdoch [62] mentioned that nitrogen fertilizers, such as urea, could suppress *S. hermonthica* germination, during conditioning application, where seeds germination of *S. hermonthica* was associated with germination stimulants secretion.

5. Cropping systems

5.1. Intercropping:

Intercropping is a facilitating method which stimulates crop production and building of soil fertility. Intercropping was used in Africa regions as a low-cost method for controlling *Striga* weeds [63]. It could help in reducing parasitic weeds or seeds bank and increasing the yields of crop in the fields with weeds infestation. The obligate witch weeds and broomrapes can be controlled with intercropping by three ways; the intercrop could reduce soil temperature and hence suppress parasitic weeds in particular *Striga* spp.; it could improve the soil fertility by nitrogen fixation or organic matter production, followed by release of nutrients which increase biological activity, such as ethylene gas, and it could produce exudates or roots which cause suicidal germination with suitable host of the parasite. Intercropping is considered to be an important tool in *Striga* management because using chemical control is difficult. Intercropping of maize with legumes could reduce weeds density in the intercrop, comparing with maize cultivated individually, this may be due to the reduction in the available light for weeds in the maize-legume intercrops [64]. Similarly, Khan *et al*. [65] revealed that when maize or sorghum were intercropped with fodder leguminous, *Desmodium uncinatum* and *Desmodium intortum*, it significantly reduced *S. hermonthica* infestation and increased the yield of grains. Moreover, when *Eleusine coracana* (finger millet) was intercropped with *D. intortum* (green leaf *Desmodium*), *S. hermonthica* counts were reduced in the intercrops than in the mono-crops [66].

Fasil *et al.*, [67] found that *Striga* emergence in sorghum-cowpea intercropping system was lower than in sole crops. Generally, intercropping cereals with legumes *e.g*. cowpea, peanut or green-gram could reduce *Striga* numbers [68]. Recently, the intercrop of cereals with fenugreek could reduce the infection of *O. crenata* on faba bean or pea because of the allelopathic interactions [69]. *S. hermonthica* competes with sorghum for water, nutrients, space, light and photosynthates and hence it negatively affects sorghum yield. So, Dereje *et al*., [70] studied the influence of intercropping sorghum with legumes for controlling *Striga* in sorghum. Sorghum/ground nut intercrop yielded more than sorghum/soybean intercrop at all growing seasons. Intercropping groundnut in 1:1 proportion and simultaneous planting gave grater economic benefits regarding the gross income and land equivalent than sole planting, where it was found to be essential for controlling *Striga*. Intercropping canola with wheat significantly reduced the growth of broomrape depending on wheat genotype, where significant genetically variation of allelopathic activities was observed in wheat. The wild wheat genotypes were stronger in their inhibitory effect, than wheat genotypes which cultivated, where it is valuable as trap crops for Egyptian broomrape seeds bank [71]. In a field experiment, maize - wheat cropping system was undertaken on a sandy clay loam soil for three years for evaluating the impacts of conservation agriculture on crop and water productivity as well as organic carbon accumulation in the soil. In all residue retention plots, wheat residue was retained in maize crop and maize residue was retained in wheat crop under zero till conditions. Results showed that plots under permanent broad bed of residue and without residue resulted in higher maize grain yield than in conventional tillage's [72]

5.2. Trap crops

Trap crops are non-host crops that can stimulate parasite germination [73]. *Striga* infestation to cereal crops was controlled by crop rotation or intercropping with groundnut [74], cowpea [75], soybean [68], pigeon pea [76], cotton and yellow gram [63]. Van Mourik *et al*. [77] mentioned that sesame or cowpea, when applied in intercropping system, could reduce the seeds bank of *S. hermonthica* in millet fields. The rotations of green manure crops of *Cajanus cajan* or *Crotalaria ochroleuca* could improve rice yields with *S. asiatica* infestation in the field by enhancing soil fertility or root exudates which can cause suicidal germination of *Striga* seeds [59]. Sorghum , barley , maize , vetches , clover , flax , coriander , pepper , cowpea , hemp , mung bean , snap bean , alfalfa , soybean and chickpea are important crops which could reduce the seeds bank of broomrape [78, 79]. Qasem [80] applied about 44 plant species (13 families) as trap plants to reduce *O. ramosa* infestation on tomatoes, under glasshouse conditions. When tomato cultivation followed *Anethum graveolens*, *C. vulgaris*, *Cucumis melo* var. *flexuosus*, *Pimpinella anisum*, *Sesamum indicum*, *Solanum elaeagnifolium*, *Sorghum vulgare*, *Spinacia oleracea* and *T. alexandrinum*, the shoot number of the parasite on tomato was found to be the highest, while it was the lowest after *Brassica oleracea var. italica* , *Brassica rapa var. rapa*, *Capsicum annuum* , *Capsicum frutescens* , *Cicer arietinum* , *Citrullus colocynthis* , *Cucurbita maxima* , *Cuminum cyminum* , *Hordeum vulgare* , *Linum usitatissimum* , *Spinacia oleracea* cv. Epinard greant and *Vigna sinensis* cv. Savi. Also, the dry weight of parasite per shoot was the lowest on tomato grown after *C. arietinum, C. frutescens, C. melo, Hibiscus sabdariffa, P. anisum* and *T. alexandrinum,* while it was the highest after *Cichorium endivia var. crispum, Peganum harmala, S. oleracea* cv. Epinard greant and *Zea mays.* The shoot dry weight of tomato was increased by 126% over parasite free control. Considering the average of the two experiments, high tomato growth and best parasite control were obtained after *V. sinensis*. *H. sabdariffa, H. vulgare,* and *S. vulgare*.

5.3. Catch crops

Catch crop is a host plant which induces normal parasitism, but it is removed from the field after the seeds of the parasite were germinated and before the flowering stages. The parasite seeds bank can be reduced by this method in a similar way as trap crops. The potential catch crops important for controlling broomrape in faba bean are white mustard, lentil, and fenugreek [81, 82]. Numerous potential trap crops were examined *in vitro* or in small pots only, but not in the fields. *Striga* control is mostly achieved in a system of rotation with a trap crop; a crop which stimulates *Striga* seed germination but cannot be infected by the parasite. Cotton and soybean crops are the most promising trap crops reported for controlling *Striga* and *Orobanche* species. While Sudan grass is the most promising catch crop for *S. hermonthica* control [83]. To avoid the competition of the following crop, the residues of the fallow plant must be either burnt, removed, incorporated in the soil or mulched before cultivating a new growing season. The intercrop or rotation must be rotated regularly to avoid other pests' populations and development of diseases into economically harmful proportions.

Resistant crop varieties similarly reduce the infestation rates of parasitic weeds as trap crops act. These resistant crops can decrease the negative effect of the parasitic weeds on crop yields, but do not prevent the parasite from producing seeds [58].

6. Resistant crop varieties

In any weed control strategy, it is highly desirable to exploit genetic resistance. Resistance to parasitic plants can occur at different stages of the parasite lifecycle: before attachment to the host, during root penetration or after establishment of vascular connections. Resistance often appears to involve several mechanisms, but it is often weak especially in the presence of new geographic or physiologically specialized forms of the parasite. Host crop resistance towards parasitic weed was enhanced by transgenic lines; transgenes caused higher numbers of parasitism failure and hence reduction in *Phelipanche* biomass and increased host yield. Mannose 6-Phosphate Reductase (M6PR) gene regulates mannitol content in the parasite, an essential process to broomrape species for water and nutrient uptake from the host. The number of dead tubercles was also increased significantly on transgenic plants as compared with the control plants [84]. Some faba bean cultivars were moderately resistant to broomrape only and are available to farmers. The resistance components in faba bean were occurred against numbers of infective and non infective broomrape species. The common mechanisms of broomrape species may due to low seeds germination induction; negative tropism of germinated seeds from faba bean roots; necrosis of radicles with successfully contacted faba bean roots and necrosis of formed broomrape tubercles. Rubiales *et al*., [85] reported that the parasitic interaction between sunflower and *O. cumana* generally considered a gene for gene model, with resistance in sunflower and a virulence in *O. cumana* was controlled by dominant alleles at single loc.

Timko *et al*., [86] showed that resistance of dicots plants, especially cowpea, against *S. Gesnerioides* appeared to be mainly monogenic. Resistance appears to be race-specific with multiple pathotypes of *S. gesnerioides* and multiple resistance genes in the cowpea genome [87]. In most cases, resistance to *Striga* spp. in sorghum, millet and rice appeared to be polygenic with a large genotype by environment interaction [88]. The wild sorghum is an important reservoir of *Striga* resistance which could be used for explanation of the genetic basis of cultivated sorghum for resistance. The first identified and cloned resistance gene to *Striga* was encoded as CC-NBS-LRR Resistance protein (R). This suggesting that the mechanisms of host resistance against parasitic weeds is similar as those used against fungal and bacterial pathogens. Salicylic acid (SA) signalling pathway plays an important role in resistance to parasitic plants and genes encoding pathogenesis-related proteins are up regulated in a number of the resistant interactions [89]. The stem vegetative part of *Cuscuta* spp. winds around plants and penetrates the vascular bundles of the host stems through haustoria to withdraw water, carbohydrates, and other solutes. Few plants exhibit an active resistance against *Cuscuta* spp. infestation. For example, cultivated tomato (*Solanum lycopersicum*) fends off *Cuscuta reflexa* by means of a hypersensitive-type response occurring in the early penetration phase. Kaiser *et al*., [90] prepared a report on the plant–plant connection between *Cuscuta* spp. and its host plants and focused on the incompatible interaction of *C. reflexa* with tomato.

7. Conclusion

Parasitic weeds could be controlled by chemical herbicides, but this method could cause harmful effect to health and the environment. So, the application of alternative methods is necessary to avoid the harmful effect of chemical herbicides. The different alternative methods like biological control; natural products; agricultural practices and cropping systems were surveyed in this review. The following table (Table 1) summarizes the effectiveness of these methods in controlling different weeds.

Table (1) Control measures for the major global significant parasitic weeds.

Technique	Parasite		
	Striga	*Orobanche*	*Cuscuta*
Preventive			
National quarantine	+	+	+
International quarantine	+	+	+
Cultural			
Crop rotation	+	+	+
Planting date	+	+	+
Mineral fertilizer	+	−	−
Flooding	+	+	−
Organic material	+	+	−
Managed fallow	+	+	+
Physical			
Cleaning of crop seed	−	−	+
Hand weeding	+	+	+
Burning	−	−	+
Deep plowing	+	+	−
Soil solarization	+	+	+
Germination compounds	+	+	−
Biological			
Insects	−	+	−
Fungi	+	+	+
Integrated control	+	+	+
Host resistance/tolerance	+	+	−

+ Effective, – Ineffective

8. Conflicts of interest

There are no conflicts to declare

10. References

[1] Runyon, J.B.; Mescher, M.C.; Felton, G.W. and De Moraes, C.M. (2010). Parasitism by *Cuscuta pentagona* sequentially induces JA and SA defence pathways in tomato. Plant, Cell and Environment, 33:290–303.

[2] Masteling, R.; Lombard, L.; Boer, W.; Raaijmakers, J.M.; Dini-Andreote, F. (2019). Harnessing the microbiome to control plant parasitic weeds. Current Opinion in Microbiology, 49: 26-33.

[3] Aksoy, E.; Arslan, Z.F.; Tetik, O. and Eymirli, S. (2014). Utilization opportunities from allelopathic features of some catch and trap crops for controlling Egyptian broomrape [*Phelipanche aegyptiaca* (Pers.) Pomel] in tomato fields. Journal of Agricultural Sciences, 20:126 -135.

[4] Rubiales, D. and Heide-Jørgensen, H.S. (2011) Parasitic Plants. *In*: Enciclopedia of Life Sciences (ELS), John Wiley & Sons, Ltd: Chichester. ISBN: 9780470015902. DOI: 10.1002/9780470015902.a0021271.

[5] Mohamed, K.I.; Musselman, L.J. and Riches, C.R. (2001). The genus *Striga* (*Scrophulariaceae*) in Africa. Annals of the Missouri Botanical Garden, 88 (1): 60-103.

[6] Lee, K.B. and Jernstedt, J.A. (2013). Defense response of resistant host *Impatiens balsamina* to the parasitic angiosperm *Cuscuta japonica*. J. Plant Biol., 56:138-144.

[7] Mishra, J.S. (2009). Biology and Management of *Cuscuta* species. Indian J. Weed Sci. 41 (1 & 2): 1-11.

[8] Fernández-Aparicio, Mónica; Delavault, P. and Timko, M.P. (2020). Manag-ement of infection by parasitic weeds. Plants, 9: 1184.

[9] Goldwasser, Y. and Rodenburg, J. (2014). Integrated agronomic management of parasitic weed seed banks, DOI:10.1007/978-3-642-38146-1_22

[10] Sauerborn, J., Müller-Stöver, D. and Hershenhorn, J. (2007). The role of biological control in managing parasitic weeds. Crop Prot., 26: 246–254.

[11] Zermane, N.; Souissi, T.; Kroschel, J. and Sikora, R. (2007). Biocontrol of broomrape (*Orobanche crenata* Forsk. and *Orobanche foetida* Poir) by *Pseudomonas fluorescens* isolate Bf 7-9 from the faba bean rhizosphere. Biocontrol Sci. Technol., 17:483–497.

[12] Bond, W.; Turner, R.J. and Grundy, A.C. (2003). A review of non-chemical weed management. The Organic Association. http:// www. organic weeds. org.uk.

[13] Kremer, R.J. (2005).The role of bioherbicides in weed management. Biopestic. Int., 1(3,4): 127-141.

[14] Chen, J.; Ma, Y, Q. and XuE, Q. H. (2018). Use of microorganisms in controlling parasitic root weed *Orobanche* spp. (J). Chinese Journal of Eco-Agriculture, 26(1): 49-56.

[15] Boari, A. and Vurro, M. (2004). Evaluation of *Fusarium* spp. and other fungi as biological control agents of broomrape (*Orobanche ramosa*). Biol. Control, 30: 212–219.

[16] Marley, P.S.; Ahmed, S.M.; Shebayan, J.A.Y. and Lagoke, S.T.O. (1999). Isolation of *Fusarium oxysporum* with potential for biocontrol of the witchweed (*Striga hermonthica*) in the Nigerian Savanna. Biocontrol Sci. Technol., 9:159–163.

[17] Hess, D.E.; Kroschel, J.; Traore´, D.; Elzein, A.E.M.; Marley, P.S.; Abbasher, A.A. and Diarra, C. (2002). *Striga*: biological control strategies for a new millennium. *In*: Sorghum and Millet Diseases 2000, Leslie, J.F. (Ed.), Iowa State Press, Ames, Iowa, USA, pp. 165–170.

[18] Amsellem, Z.; Barghouthi, S.; Cohen, B.; Goldwasser, Y.; Gressel, J.; Hornok, L.; Kerenyi, Z.; Kleifeld, Y.; Klein, O.; Kroschel, J.; Sauerborn, J.; Mu¨ ller-Sto¨ ver, D.; Thomas, H.; Vurro, M. and Zonno, M. (2001). Recent advances in the biocontrol of *Orobanche* (broomrape) species. BioControl, 46: 211-228.

[19] Shabana, Y.M.; Mùller-Stöver, D. and Sauerborn, J. (2003). Granular Pesta formulation of *Fusarium oxysporum* f. sp. *orthoceras* for biological control of sunflower broomrape: efficacy and shelf-life. Biol. Control, 26: 189–201.

[20] Marley, P.S.; Aba, D.A.; Shebayan, J.A.Y.; Musa, R. and Sanni, A. (2004). Integrated management of *Striga hermonthica* in sorghum using a mycoherbicide and host plant resistance in the Nigerian Sudano-Sahelian savanna. Weed Res., 44:157–162.

[21] Cohen, B.; Amsellem, Z.; Lev-Yadun, S. and Gressel, J. (2002). Infection of tubercles of the parasitic weed *Orobanche aegyptiaca* by mycoherbicidal *Fusarium* species. Ann. Bot., 90: 567–578.

[22] Ghannam, I.; Barakat, R. and Al-Masri, M. (2007). Biological control of Egyptian broomrape (*Orobanche aegyptiaca*) using *Fusarium* spp. Phytopathol. Mediterr. , 46, 177–184.

[23] Dor, E., Hershenhorn, J., Andolfi, A. *et al.* (2019). *Fusarium verticillioides* as a new pathogen of the parasitic weed *Orobanche* spp. Phytoparasitica, 37: 361–370.

[24] Beed, A.D.; Hallett, S.G.; Venne, J. and Watson, A. (2007). Biocontrol using *Fusarium Oxysporum:* A critical component of integrated *Striga* management. *In book:* Integrating New Technologies for *Striga* Control (pp.283-300). DOI: 10.1142/978 9812771506_0021

[25] Zahran, E.B. (2008). Biological Control of *Striga hermonthica* (Del.) Benth. Using Formulated Mycoherbicides Under Sudan Field Conditions. Ph.D Thesis, University of Hohenheim, Germany: 2008, pp: 143.

[26] Ndambi, B.; Cadisch, G. ; Elzein, A. and Heller, A. (2011). Colonization and control of *Striga hermonthica* by *Fusarium oxysporum* f. sp. *strigae*, a mycoherbicide component: An anatomical study. Biological Control , 58(2): 149-159.

[27] Ciotola, M.; Watson, A.K. and Hallett, S.G. (1995). Discovery of an isolate of *Fusarium oxysporum* with potential to control *Striga hermonthica* in Africa. Weed Res., 35: 303–309.

[28] Marley P.S.; Kroschel. J. and Elzein, A. (2005). Host specificity of *Fusarium oxysporum* Schlect (isolate PSM 197), a potential mycoherbicide for controlling *Striga* spp. in West Africa. Weed, 45(6):407-412.

[29] Nzioki, H.S.; Oyosi, F.; Morris, C.E. ; Kaya, E.; Pilgeram, A. L.; Baker, C.S. and Sands, D.C. (2016). *Striga* biocontrol on a toothpick: A readily deployable and inexpensive method for smallholder farmers. Frontiers in Plant Science, Article 1121.

[30] Wang, R. (1986). Current status and perspectives of biological weed control in China. Chinese J. Biol. Contr., 1: 173-77.

[31] Fallahpour, F.; Koocheki, A.; Mahallati, M.N.; Rastegar, M.F. and Ghorbani, R. (2016). Biological control of dodder (*Cuscuta campestris* L.) by fungi pathogens. Būm/shināsī-i kishāvarzī, 2(3): 408-416.

[32] Al-Ani L.K.T. (2018) *Trichoderma*: Beneficial Role in Sustainable Agriculture by Plant Disease Management. *In*: Plant Microbiome: Stress Response. Microorganisms for Sustainability, Egamberdieva D., Ahmad P. (eds) Vol 5. Springer, Singapore.

[33] Nawar, Lobna, S. and Sahab, A. F. (2011). Evaluation of compost fortified with *Trichoderma* spp. isolates as biological agents against broomrape of chamomile herbs. Nature and Science, 9(8):229-236.

[34] El-Dabaa, M.A.T. and Abd-El-Khair, H. (2020). Applications of plant growth promoting bacteria and *Trichoderma* spp. for controlling *Orobanche crenata* in faba bean. Bulletin of the National Research Centre, 44:4.

[35] El-Dabaa, M.A.T.; Haggag, Karima, H.E. and El-Mergawi, R.A. (2021). Application of *Trichoderma* spp. in controlling *Orobanche ramosa* parasitism in chamomile. Middle East Journal of Applied Sciences, 11 (1): 360-367.

[36] Hassan, M.N.; Azrag, Mona, A.; Rugheim, A.M.E. and Abusin, Rashida (2019). Performance of *Trichoderma harzianum* on *Striga hermonthica* and sorghum bicolor growth. Internationa,l 8(3):195-206.

[37] Kannan, C.; Kumar, B.; Aditi, P. and Gharde, Y.(2014). Effect of native *Trichoderma viride* and *Pseudomonas fluorescens* on the development of *Cuscuta campestris* on chickpea, *Cicer arietinum* . Journal of Applied and Natural Science, 6 (2): 844 - 851.

[38] Klein, O. and Kroschel, J. (2002). Biological control of Orobanche spp. with *Phytomyza orobanchia*, a review. BioControl, 47: 245–277.

[39] Balah, M.A. (2020). Weed control ability of Egyptian natural products against annual, perennial and parasitic weeds. Acta Ecologica Sinica, 40: 492–499.

[40] Briache, Fatima, Z.; Ennami , Mounia; Mbasani-Mansi, J. ; Lozzi, Assia ; Abousalim, A. ; El Rodeny, W. ; Amri, M.; Triqui, Z.E. and Mentag, R. (2020). Effects of salicylic acid and indole acetic acid exogenous applications on induction of faba bean resistance against *Orobanche crenata*. Plant Pathol. J., 36(5): 476-490.

[41] Messiha, Nadia, K.; El-Dabaa, M.A.T.; El-Masry; R.R. and Ahmed, S.A.A. (2018). The allelopathic influence of *Sinapis alba* seed powder (white mustard) on the growth and yield of *Vicia faba* (faba bean) infected with *Orobanche crenata* (broomrape). Middle East Journal of Applied Sciences, 8 (2): 418-425.

[42] El-Dabaa, M.A.T.; Ahmed, S.A.A.; Messiha, Nadia, K. and El-Masry, R.R. (2019).The allelopathic efficiency of *Eruca sativa* seed powder in controlling *Orobanche crenata* infected *Vicia faba* cultivars. Bulletin of the National Research Centre, 43:37.

[43] El-Masry, R.R.; El-Desoki, E.R.; El-Dabaa, M.A.T.; Messiha, Nadia, K and Ahmed, S.A.A. (2019). Evaluating the allelopathic potentiality of seed powder of two *Brassicaceae* plants in controlling *Orobanche ramosa* parasitizing *Lycopersicon esculentum* Mill. Plants. Bulletin of the National Research Centre, 43:101.

[44] Zeid, M.M. and Komeil, Doaa, A. (2019). Same-hill intercropping of different plant species with faba bean for control of *Orobanche crenata*. Alexandria Science Exchange Journal, 40(2):228-238.

[45] Ahmed, S.A.; Messiha, Nadia, K., El-Masry, R.R. and El-Dabaa, M.A.T. (2020). The dual allelopathic capacity of two *Brassicaceae* plants seed powder in controlling *Orobanche crenata* infesting *Pisum sativum* as well as stimulating its growth and yield. Bulletin of the National Research Centre, 44:17.

[46] Snapp, S.S.; Swinton, S.M.; Labarta, R.; Mutch, D.; Black, J.R.; Leep, R.; Nyiraneza, J. and O'Neil, K. (2005). Evaluating cover crops for benefits, costs and performance within cropping system niches. Agronomy Journal, 97 (1): 322–32.

[47] Schnell, H.; Kunisch, M.; Saxena, M.C. and Sauerborn, J. (1996). Simulation of the seed bank dynamics of *Orobanche crenata* Forsk. in some crop rotations common in northern Syria. Exp. Agric. 32: 395–403.

[48] Ouédraogo, O.; Neumann, U.; Raynal, R. A.; Sallé, G.; Tuquet, C. and Dembélé, B. (1999). New insights concerning the ecology and the biology of *Rhamphica rpafistulosa* (*Scrophulariaceae*).Weed Res., 39:159–169.

[49] Rodenburg, J.; Bastiaans, L.; Kropff, M.J. and Van Ast, A. (2006). Effects of host plant genotype and seed bank density on *Striga* reproduction. Weed Res., 46:251–263.

[50] Rodenburg, J.; Riches, C.R. and Kayeke, J.M. (2010). Addressing current and future problems of parasitic weeds in rice. Crop Prot., 29:210–221.

[51] Van Ast, A.; Bastiaans, L. and Katile, S. (2005). Cultural control measures to diminish sorghum yield loss and parasite success under *Strigahe rmonthica* infestation. Crop Prot 24:1023–1034.

[52] Van Delft, G.J.; Graves, J.D.; Fitter, A.H. and Van Ast, A. (2000). *Striga* seed avoidance by deep planting and no-tillage in sorghum and maize. Int. J. Pest Manag. , 46:251–256.

[53] Rubin, B.; Cohen, O. and Gamliel, A. (2008). Soil solarization an environmentally-friendly alternative, Part III. http://www.fao.org/3/a-i0178e /i0178e02.pdf.

[54] Katan, J.; Greenberger, A.; Alon, H. and Grinstein, A. (1976). Solar heating by polyethylene mulching for control of diseases caused by soil-borne pathogens. Phytopathology, 66:683–688.

[55] Mauromicale, G.; Lo Monaco, A.; Longo, A.M.G. and Restuccia A (2005). Soil solarization, a nonchemical method to control branched broomrape (*Orobanche ramosa*) and improve the yield of greenhouse tomato. Weed Sci., 53:877–883.

[56] Mauromicale, G., Restuccia, G., and Marchese, M. (2001). Soil solarisation, a non-chemical technique for controlling *Orobanche crenata* and improving yield of faba bean. Agronomie, 21: 757–765.

[57] Jamil, M.; Kanampiu, F.K.; Karaya, H.; Charnikhova, T. and Bouwmeester, H.J. (2012). *Striga hermonthica* parasitism in maize in response to N and P fertilisers. Field Crop Res., 134:1–10.

[58] Rodenburg, J. and Bastiaans, L (2011). Host-plant defence against Striga spp.: reconsidering the role of tolerance. Weed Res., 51:438–441.

[59] Riches, C.R.; Mbwaga, A.M.; Mbapila, J. and Ahmed, G.J.U. (2005). Improved weed management delivers increased productivity and farm incomes from rice in Bangladesh and Tanzania. Aspect. Appl. Biol., 75:127–138.

[60] Parker, C. (2009). Observations on the current status of *Orobanche* and *Striga* problems worldwide. Pest Manag. Sci., 65:453–459.

[61] Kamara, A.Y.; Ekeleme, F.; Menkir, A.; Chikoye, D. and OmoiguiL, O. (2009). Influence of nitrogen fertilization on the performance of early and late maturing maize cultivars under natural infestation with *Striga hermonthica*. Archives of Agronomy and Soil Science, 55(2):125–145.

[62] Dzomeku, I.K. and Murdoch, A.J. (2007). Effects of prolonged conditioning on dormancy and germination of *Striga hermonthica*. Journal of Agronomy, 6:29-36.

[63] Oswald, A., Ransom, J.K., Kroschel, J., Sauerborn, J. (2002). Intercropping controls *Striga* in maize based farming systems. Crop Prot., 21:367–374.

[64] Bilalis, D.; Papastylianou, P.; Konstantas, A.; Patsiali, S.; Karkanis, A. and Efthimiadou, A. (2010).Weed-suppressive effects of maize-legume inter-cropping in organic farming. Int. J. Pest Manag., 56:173-181.

[65] Khan, Z.R.; Pickett, J.A.; Hassanali, A.; Hooper, A.M. and Midgea C.A.O.(2008). *Desmodium* species and associated biochemical traits for controlling *Striga* species: Present and future prospects. Weed Research, 43: 302- 306.

[66] Odhiambo, G.D, and Ransom, J.K. (1993). Effect of dicamba on the control of *Striga hermonthica* in maize in western Kenya. African Crop Science Journal, 1:105-110.

[67] Fasil, R.; Verkleij, J.A.C. and Ernst, W.H.O. (2005). Intercropping for the improvement of sorghum yield, soil fertility and *Striga* control in the subsistence agriculture region of Tigray (Northern Ethiopia). Journal of Agronomy and Crop Science, 191:10-19.

[68] Carsky, R.J.; Berner, D.K.; Oyewole, B.D.; Dashiell, K. and Schulz S (2000). Reduction of *Striga hermonthica* parasitism on maize using soybean rotation. Int. J. Pest Manag., 46:115–120.

[69] Fernández-Aparicio, M., Emeran, A.A. and Rubiales, D. (2008). Control of *Orobanche crenata* in legumes intercropped with fenugreek (*Trigonella foenum-graecum*). Crop Prot., 27: 653–659.

[70] Dereje , G.; Adisu , T.; Mengeshaer, M. and Bogale, T. (2016). The influence of intercropping sorghum with legumes for management and control of *Striga* in sorghum at Assosa Zone, Benshangul Gumuz Region, Western Ethiopia, East Africa. Adv. Crop Sci. Tech., 4(5): 238.

[71] Razavifar, Zeynab; Karimmojeni, H. and Ghorbanifar, Fatimah, S. (2017). Effects of wheat-canola intercropping on *Phelipanche aegyptiaca* parasitism. Journal of Plant Protection Research, 57 (3), DOI: 10.1515/jppr-2017-0038.

[72] Das, T.K.; Saharawat, Y.S.; Bhattacharyya, R.; Sudhishri, S.; Bandyo-padhyay, K.K.; Sharmac, A.R. and Jat, M.L. (2018). Conservation agriculture effects on crop and water productivity, profitability and soil organic carbon accumulation under a maize-wheat cropping system in the North-Western Indo-Gangetic Plains. Field Crops Research, 215:222–231.

[73] Goldwasser, Y.; Kleifeld, Y.; Plakhine, D. and Rubin, B. (1997).Variation in vetch (*Vicia* spp.) response to *Orobanche aegyptiaca*. Weed Sci., 45:756–762.

[74] Carson, A.G. (1989). Effect of intercropping sorghum and groundnuts on density of *Striga*

hermonthica in the Gambia. Trop. Pest Manag., 35:130–132.

[75] Carsky, R.J.; Singh, L. and Ndikawa, R. (1994). Suppression of *Striga hermonthica* on sorghum using a cowpea intercrop. Exp. Agric., 30:349–358.

[76] Oswald, A. and Ransom, J.K. (2001). *Striga* control and improved farm productivity using crop rotation. Crop Prot., 20:113–120.

[77] Van Mourik, T.A.; Bianchi, F.J.J.A.; Van Der Werf, W. and Stomph, T.J. (2008). Long-term management of *Striga hermonthica*: strategy evaluation with a spatio-temporal population model. Weed Res., 48:329–339.

[78] Kleifeld, Y.; Goldwasser, Y.; Herzlinger, G.; Joel, D.M.; Golan, S and Kahana, D, (1994). The effects of flax (*Linumus itatissimum*) and other crops as trap and catch crops for control of Egyptian broomrape (*Orobanche aegyptiaca* Pers.). Weed Res., 34:37–44.

[79] Abebe, G.G.; Sahile, A. and Al-Tawaha, A.R.M. (2005). Evaluation of potential trap crops on *Orobanche* soil seed bank and tomato yield in the central rift valley of Ethiopia. World J. Agric. Sci., 1:148–151.

[80] Qasem, J.R. (2019). Branched broomrape (*Orobanche ramosa* L.) control in tomato (*Lycopersicon esculentum* Mill.) by trap crops and other plant species in rotation. Crop Protection, 120: 75–83.

[81] Acharya, B.D.; Khattri, G.B.; Chettri, M.K. and Srivastava. S.C. (2002). Effect of *Brassica campestris* var. *toria* as a catch crop on *Orobanche aegyptiaca* seed bank. Crop Prot., 21:533–537.

[82] Fernandez-Aparicio, M.; Emeran, A.A. and Rubiales, D. (2010). Inter-cropping with berseem clover (*Trifolium alexandrinum*) reduces infestation by *Orobanche crenata* in legumes. Crop Prot., 29:867–871.

[83] Oswald, A., Ransom, J.K., Kroschel, J. and Sauerborn, J. (1999). Developing a catch-cropping technique for small-scale subsistence farmers. *In* : *Advances in Parasitic Weed Control at On-farm Level.* Vol. 1. Joint action to Control *Striga* in Africa, Kroschel, J. Mercer-Quarshie, H. & Sauerborn, J. (eds). Margraf Verlag, Weikersheim, Germany, *pp*. 181-187.

[84] Aly, R. (2012). Advanced Technologies for Parasitic Weed Control. Weed Science 60(2): 290-294.

[85] Rubiales, D.; Fernández-Aparicio, M.; Vurro, M. and Eizenberg, H. (2018). Editorial: Advances in Parasitic Weed Research. Frontiers in Plant Science, 9: Article 236.

[86] Timko, M.; Gowda, B.S.; Ouédraogo, J. and Ousmane, B. (2007).Molecular markers for analysis of resistance to *Striga gesnerioides* in cowpea. *In*: Integrating New Technologies for *Striga* Control; World Scientific Publishing Co Pte Ltd.: Singapore, pp. 115–128.

[87] Ohlson, E.W. and Timko, M.P. (2020). Race structure of cowpea witchweed (*Striga gesnerioides*) in West Africa and its implications for *Striga* resistance breeding of cowpea. Weed Sci., 68:125–133.

[88] Scholes, J.D. and Press, M.C. (2008). *Striga* infestation of cereal crops-An unsolved problem in resource limited agriculture. Curr. Opin. Plant Biol., 11:180–186.

[89] Yoder, J. and Scholes, J.D. (2010). Host plant resistance to parasitic weeds; recent progress and bottlenecks. Current Opinion in Plant Biology 13(4):478-484.

[90] Kaiser , B.; Vogg , G.; Fürst , U.B. and Albert , M. (2015). Parasitic plants of the genus *Cuscuta* and their interaction with susceptible and resistant host plants. Front. Plant Sci., 6 :Article 45.