Crenate Broomrape (*Orobanche crenata* Forsk.) Problem and its Management in Food Legumes

Negussie Tadesse[1*], Seid Ahmed[1], Fikremariam Asargew[2], Cherenet Alem[2], Mekonnen Misganaw[3], Teklay Abebe[4], Anteneh Ademe[5], Gemechu Keneni[6], Gashaw Belay[7], Yohannes Ebabuye[5], Bogale Niger[3], Rezene Fessehaie[8]

[1]*EIAR, Debre Zeit Agricultural Research Center, P.O. Box 32, Debre Zeit, Ethiopia*
[2]*ARARI, Adet Agricultural Research Center, P.O. Box 527, Bahir Dar, Ethiopia*
[3]*ARARI, Sirinka Agricultural Research Center, P.O. Box 74, Weldia, Ethiopia*
[4]*TARI, Alamata Agricultural Research Center, P.O. Box 56, Alamata, Ethiopia*
[5]*ARARI, Gondar Agricultural Research Center, P.O. Box 1337, Gondar, Ethiopia*
[6]*EIAR, Holetta Agricultural Research Center, P.O. Box 2003, Addis Ababa, Ethiopia*
[7]*Amhara Region Agricultural Research Institute (ARARI), P.O. Box 527, Bahir Dar, Ethiopia*
[8] *rezenefesseha@gmail.com* Corresponding author: negussie_ab@yahoo.com*

Abstract

*Crenate broomrape (***Orobanche crenata Forsk***.) has become an alarming constraint to highland food legumes production in the northern parts of Ethiopia since the 1980s. Recent, surveys and field experiments on cultural, chemical, fertilizer and host plant resistance methods of controlling the parasite using faba bean (***Vicia faba L***.) as a test crop conducted by Adet, Alamata, Gondar and Sirinka Agricultural Research Centers revealed that O. crenata was widely distributed in major highland food legumes growing areas, the most affected districts of the South Wollo Zone being Dessie Zuria, Kutaber, Tenta and Mekdela where farmers in these four districts lose hope to the extent of abandoning growing faba bean. The population density of the parasite could range between 50 and 250 shoots m^{-2} in some of the heavily infested districts such as Mekdela and Tenta. Two other districts in South Wollo: (Legambo and Delanta) are also Orobanche risk areas. Likewise, in South Gondar the most affected districts are Tatch Gayint and Farta. The parasitic weed affected faba bean, field pea, lentil and to a lesser extent chickpea and grass pea crops including other weedy wild hosts. Mixed cropping of faba bean with Fenugreek and Lepidium, which are not affected by the parasitic weed did not protect faba bean from infections. Increased levels of inorganic (nitrogen) and manure applications reduced Orobanche infection. Integrating tolerant cultivar Hashengie (ILB-4358) and 1-2 sprays of sub-lethal glyphosate herbicide at flowering stages were found to be effective in managing Orobanche in faba bean and increased seed yield up to 3 t ha^{-1}.*

Keywords: Crenate broomrape, Ethiopia, faba bean, *Orobanche crenata*

Introduction

Parasitic weeds of the genus *Orobanche* (Orobanchaceae) are becoming major threats to the production of highland food legumes, in particular the crenate broomrape (*Orobanche crenata* Forsk) to faba bean in Ethiopia (Tadesse *et al*., 1999; Fessehaie and Nefo, 2009; Abebe *et al*., 2013). Other parasitic weeds attacking food legumes such as chickpea, faba bean and lentil include the dodders (*Cuscuta* spp.) (Fessehaie and Nefo, 2009). *O. crenata* was first detected in Dessie Zuria and Kutaber Districts in the early 1980s (Tadesse *et al*., 1999). Earlier survey results indicated that *O. crenata* is and to be an actual and potential threat to highland food legumes production particularly with more pronounced effect in faba bean and field pea (Fessehaie and Nefo, 2009). Of the highland food legumes growing areas of the country, two regions (Amhara and Tigray) were in severe infestation of this species (Tadesse *et al.*, 1999; Fessehaie and Nefo, 2009). The spread of this species in both regions within few years of its discovery demonstrates that a joint program to contain, control and if possible eradicate this parasite found essential as suggested by several authors (Fessehaie, 1998; Fessehaie and Nefo, 2009). However, being no adequate efforts have been made to implement the suggestions, the infestation of the weed has reached at the pick and causing considerable damage on susceptible crops (faba bean in particular). Many farmers already have been forced to abandon the growing of this crop in both regions.

There have been different *Orobanche* control methods including cultural methods, chemical control, breeding for resistant host plants etc., reported from elsewhere around the world. However, no single technology standalone reported would completely control this parasitic weed; and therefore, integrated parasitic weed management is the feasible approach that should be implemented to cope with the parasite (Rubiales and Fernández-Aparicio, 2012).

So far, surveys and field experiments on cultural, chemical, fertilizer (plant nutrition) and host plant resistance methods of controlling the parasitic weed using faba bean as a test crop have been conducted by Adet, Alamata, Gondar and Sirinka Agicultural Research Centers; and results from these experiments were reported by the respective Research Centers. Therefore, the aim of this paper is to review recent advances of studies on *O. crenata* problems and its management in food legumes production areas of the northern Highlands of Ethiopia.

Spatial distribution of the parasite and its genetic diversity

Distribution

Broomrape infested areas reported in Ethiopia are mostly in the northern parts of the country (Figures 1 and 2) especially fields with typical light soil (non-Vertisol) and altitudes ranging between 2300 and 2900 masl (Kemal and Olivera JR, 2016; Belay, G, 2015). In general, a couple of assumptions (theories) could explain the low incidence/infestation of Vertisols (black soils) by root parasitic weed species of *O. crenata*. The first assumption is natural systems regulation (NSR) which exploits antagonistic activity of naturally occurring microorganisms on parasitic weeds growth and development. For instance, *Fusarium solani* (causative agent of black root rot of faba bean) and *Fusarium oxysporum*, whose natural habitat is Vertisols, are reported to be pathogenic to parasitic weeds [broomrapes (Dor and Hershenhorn, 2009). The second one is asphyxiation theory which is related to the water logging nature of Vertisols, i.e. anaerobic environment, being able to inhibit either seed germination or seedling elongation due to lack of oxygen.

Results of surveys conducted in Gondar, Tigray and Wollo showed that *O. Crenata* was widely distributed in major highland food legumes growing areas, the most affected districts of the South Wollo Zone being Dessie Zuria, Kutaber, Tenta and Mekdela where farmers in these four districts abandoned growing faba bean (Kemal and Olivera JR, 2016). They further indicated the population density of the parasite could range between 50 and 250 shoots/m^2 in some of the heavily infested districts such as Mekdela and Tenta. Two other districts of South Wollo; Legambo and Delanta are also *Orobanche* risk areas. Likewise, in South Gondar the most affected districts are Tatch Gayint and Farta. The parasitic weed affected faba bean, field pea, lentil and to a lesser extent chickpea and grasspea crops including wild weedy plants such as *Rumex* spp., *Xanthium* spp and *Guizotia scabra* (Kemal and Olivera JR, 2016; Abebe *et al*., 2013; Ademe *et al*., 2017).

Genetic diversity

From samples collected during the survey, 11 simple sequence repeat (SSR) markers were identified for studying the intra- and inter-population genetic diversity in *O. crenata* (Belay, 2015), and has confirmed the existence of highest genotypic variation within the South Wollo *O. crenata* population compared to other locations. Most of the intraspecific molecular variations in *O. crenata* (97%) revealed neither among individuals or populations and nor within geographic origin (Belay *et al*., 2016) considered.

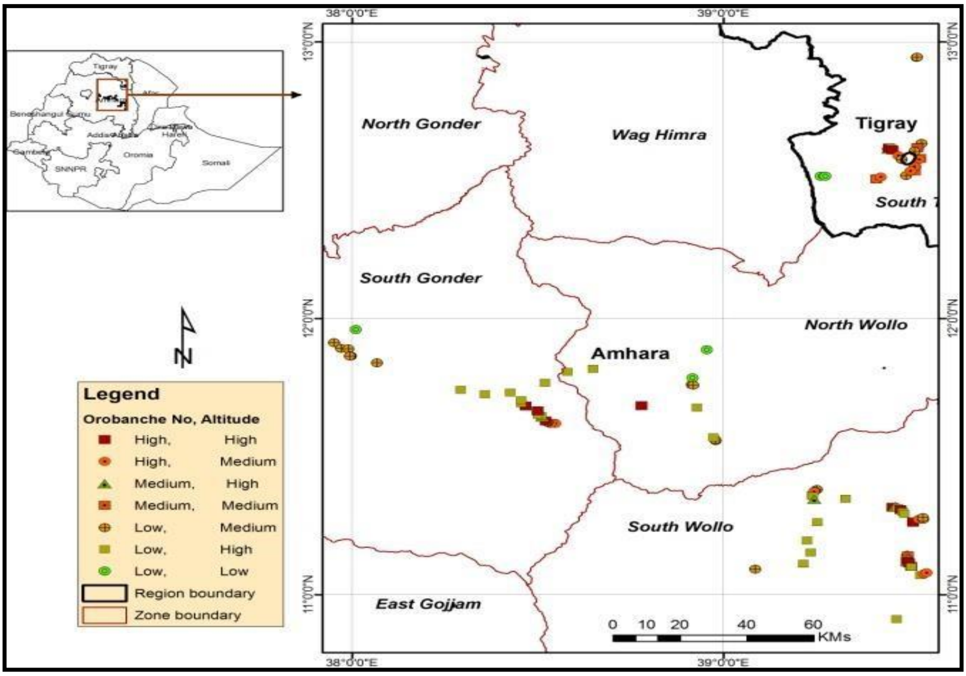

Figure 1. Distribution of *Orobanche crenata* in northern Ethiopia; Source: (Belay, 2015).

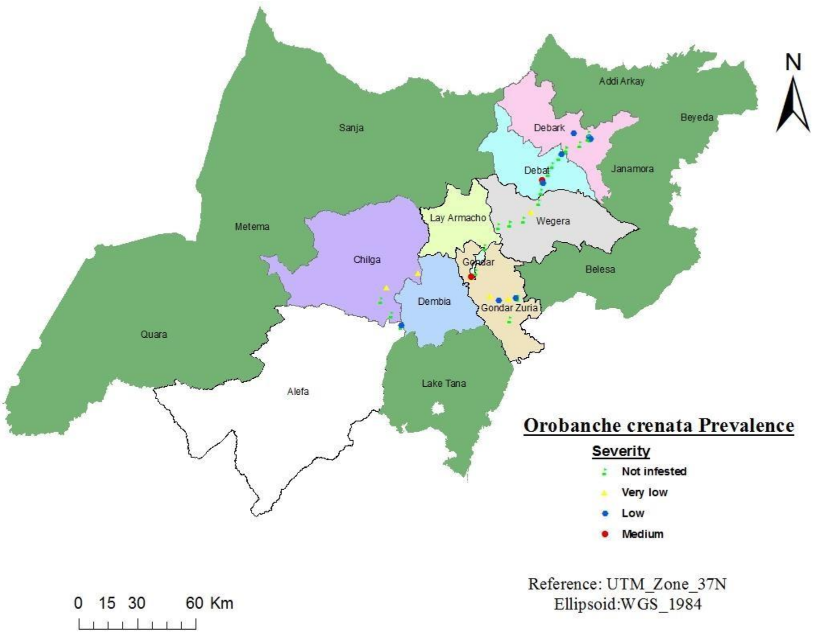

Figure. 2. Occurrence and distribution of and *Orobanche crenata* in North Gondar Districts assessed for parasitic weeds of food legumes. Very low: very few *Orobanche* shoots in the whole field, Low: few *Orobanche* shoots in the whole field, and Medium: Majority of host plants infested with 2 shoots; Source: (Ademe *et al*. 2017).

Seemingly, phenotyping of the host response is required to see if there is direct relationship between *O. crenata* genotypic variation and level of host susceptibility and/or phenotypic variation as this may have implications in resistance breeding. Although identification of primers for genotyping is a step forward, evidence on pathogenic variation (existence of host specialization and parasite races) is lacking. Knowledge on the latter is necessary for feasible progress in faba bean breeding against *O. crenata* in Ethiopia.

Control Methods

Avoiding seeds of parasitic weeds before their spread to new fields and areas through quarantine is the best documented preventive method. However, if a field is infested with parasitic weeds then a range of measures need to be employed in a combined manner, and these include sanitation and methods to prevent damage caused by the parasite and deplete the parasite seed bank in soil. In this connection, measures that have been tested and worked well in Ethiopia are reviewed in this section.

Host plant resistance

An indication of resistance to *O. crenata* is available within Ethiopian faba bean germplasm. Approximately, 10% of a gene pool, comprising of about 3000 genotypes, was reported to possess some level of resistance to *O. crenata* (Abebe *et al.*, 2015). Identification of the source of resistance was made using a field plot naturally infested with *O. crenata* at Ofla, South Tigray, Ethiopia. Tolerance to *O. crenata* was discovered after screening a number of genotypes received from ICARDA in the form of Faba bean International *Orobanche* Nursery (FBION). Genotypes Sel.F7/8975/05, ILB 4358, Giza 843 and Amcor appeared to be promising. Subsequent to repeated field evaluation and confirmation by the Alamata Agricultural Research Center, genotype ILB 4358 was released under the name Hashengie as an *Orobanche* tolerant faba bean variety in Ethiopia in 2015 (MoANR, 2016). This new variety (Hashengie) is moderately resistant to Chocolate spot and *Ascochyta* blight and moderately susceptible to faba bean Gall.

Several resistance mechanisms have been reported which can be used in faba bean breeding for resistance to *O. crenata*. These include: pre-attachment mechanism such as low induction of parasite seeds germination (Ejeta, 2007) and chemotropism, a wrong orientation of germinated *O. crenata* seeds within the potentially infective distance, (Pérez-de-Luque *et al.*, 2005a), pre-haustorial mechanisms of resistance consisting in lignifications of endodermal cells (Pérez-de-Luque *et al.*, 2005b), and post-haustorial resistance mechanisms, where attached parasites fail to develop due to chemical response consisting on delivery of toxic compounds such as phenolics into the host vascular system causing death of *O. crenata* tubercles on chickpea (Rubiales and Fernández-Aparicio, 2012).

Chemical control

Glyphosate, imidazolinones or sulfonylureas are the herbicides that are in use for parasitic weed control (Joel *et al*., 2007). Control of broomrape by foliar applications of glyphosate at low rates is recommended for faba bean (Mesa-García and García-Torres, 1985; Sauerborn *et al*., 1989). However, problem of phytotoxicity can arise due to non-selective nature of the chemical. Although little is known about the existence of tolerance to treatment of herbicides suitable to broomrape control in Ethiopian cool season food legumes germplasms, advances in multi-locational herbicides testing demonstrated the presence of tolerance to post-emergence treatment of glyphosate (72-144 g/ha) in faba bean cultivars Degaga and Hashengie (Kemal and Olivera JR. 2016; Misganaw, 2016).

Two foliar applications of glyphosate [Glyphosate-Isopropyl amine salt (144 g/ha)] are recommended, with the first application when faba bean is at early flowering stage when the parasite, *Orobanche crenata*, usually starts to appear above-ground (at emergence period) after completing attachment on faba bean root, followed by a second application 1-2 weeks later (Tadesse *et al*., 2015; Kemal and Olivera JR., 2016). The low dose of the systemic herbicide, glyphosate, is not degraded by the crop, instead it is absorbed through leaves and roots of the host plant, faba bean, with rapid translocation to the attached parasite which acts as a strong sink (Colquhoun *et al*., 2006; Pérez-de-Luque and Rubiales, 2009).

Cultural control

Early plantings of faba bean are more severely infected by *O. crenata* than delayed sowings of the crop in the infested areas of South Gondar, Ethiopia (Kemal and Olivera JR, 2016). However, experimental data from Tatch Gayint District (South Gondar Zone) indicate that delayed sowings result in reduced seed size and yield compared to early plantings. Perhaps, this might be due to sub-optimal (shortened) grain filling period remaining in the season. Therefore, other control methods need to be employed to combine the yield benefit of early plantings with a decreased *O. crenata* infestation.

Hand weeding, burning, production shift to small-grain cereals (barley, wheat and tef), crop rotation, intercropping, cultivation of the soil (ploughing), fallowing and manure application are the traditional methods smallholder farmers are using to control the parasitic weed in South Gondar Zone (Kemal and Olivera JR, 2016).

The possibility of controlling *O. crenata* in faba bean using nitrogen compounds and manure fertilization, and Rhizobium inoculant was investigated in Tatch Gayint District by Adet Agricultural Research Center. Results of this experiment revealed that of all the fertilizer components tested; only nitrogen fertilization at 75 kg N ha^{-1} can reduce *O. crenata* infection on faba bean with substantial increase of crop grain yield (Kemal and Olivera JR, 2016). In general, nitrogen in ammonium form is reported to affect negatively root parasitic weed germination and/or elongation of the seedling radicle (Rubiales and Fernández-Aparicio, 2012).

Integrated parasitic weed management (IPWM)

No single control method alone would provide satisfactory parasitic weeds management. Instead, employing a range of measures in integration, to prevent crop loss due to the parasites and eradicating the parasites seed bank in soil, is the only feasible approach to successfully manage the weeds. In this respect, credible achievement has been scored by the Sirinka Agricultural Research Center. The management of *O. crenata* in faba bean through integration of recommended control methods: employing host plant resistance (faba bean cv Hashengie), two applications of reduced rate of glyphosate (144 g ha^{-1}) and hand weeding before the parasitic weed flowers have been demonstrated (Negussie *et al.*, 2015; Figure 3).

Figure 3. Plots of Demonstration on Integrated Management of *O. crenata* in faba bean, Kutaber District, South Wollo Zone, Ethiopia; (*from top to bottom*): **[A]** stakeholders visiting the demonstration site; **[B]** (*foreground*) faba bean severely infected and damaged by *O. crenata*, (*background*) faba bean slightly infected by the parasite – (improved practice: integrated parasitic weed management). (Photo courtesy: Mulugeta Alemayehu).

IPWM Extension

An extension manual on IPWM in highland food legumes has been prepared, in local language, for use by farmers, extension workers and development agents as a guide in controlling *O. crenata* in faba bean. The manual was jointly prepared by ICARDA, ARARI and EIAR with a financial support of the Brazilian Agricultural Research Corporation (EMBRAPA) through ICARDA. The manual is intended for distribution to users in the *Orobanche* prone areas. This manual is also proposed to be made available on-line via ARARI and EIAR websites.

Conclusions

Notable parasitic weed control methods that can assist to re-introduce faba bean production in the *O. crenata* affected areas of the northern highlands of Ethiopia were developed. The control methods which will likely to be adopted by smallholder farmers are: tolerant variety, chemical control and nitrogen fertilization. It is expected that farmers will adopt the parasitic weed control technologies as a whole (whole adoption) which is essentially equivalent to adoption of integrated *O. crenata* management approach, because adoption of a single control technology alone would not bring about the desired control level. Further research is required to develop new control methods and narrow the existing knowledge rift. Thus, there is a very pressing need for more intensive studies in the following areas (*among others*): continuing and expanding the inventory, mapping and monitoring of *O. crenata* on the already identified affected areas including other uncovered important highland food legumes production areas assumed for risk of invasion; generating new information on the parasitic weed ecology and host interactions on faba bean and other important highland food legumes; strengthening the identification of research areas mainly on trap crops (non-host economical crops) and the need to study their mechanism of resistance and roles in establishing appropriate rotations that can minimize *Orobanche* seed bank; continuing and strengthening the development of IPWM and partially resistant genotypes of faba bean and lentil through research partnership among national and international partners. Surely, all these will play a significant role in minimizing faba bean yield losses due to *O. crenata*.

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