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Distribution and Severity of Crenate Broomrape (*Orobanche crenata*) on Faba Bean (*Vicia faba*) in Northern Highlands of Ethiopia

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Abstract

A root holo-parasite, crenate broomrape (Orobanche crenata Forskal) becomes a major threat for faba bean (Vicia faba L.) production in northern highlands of Ethiopia. Information on distribution and problem of crenate broomrape can help to design suitable management options to reduce its negative impact in already infested areas and further spread to new areas. To determine the weed species status in the crop fields, biophysical survey on the parasitic plants' spatial distribution and infection was conducted in small holder farmers' faba bean fields of Amhara and Tigray National Regional States in 2018 cropping season. The crenate broomrape was found in all surveyed districts of the regions; Farta, Fogera, Tach-Gaint, Dessie-Zuria, Kutaber, Mekdela, Tenta, Enda-Mahony and Ofla district with varying density and infection levels. Maximum mean density of 60 and 44 crenate broomrape shoots per square meter, and infection of 1.35 and 1.15 shoots of the parasite per faba bean plant were recorded in Dessie-Zuria and Tenta districts, respectively. Therefore, the crenate broomrape is a serious problem for faba bean production and requires appropriate management strategy for sustainable production and productivity of the crop in the area.

Keywords: density, food legume, holo-parasite, infection severity

Introduction

Faba bean (*Vicia faba* L.) is cultivated mainly for food as the major source of protein, and also for its cash value, animal feed and pest breaking role in cereal-based cropping systems of Ethiopia. The productivity of faba beans is about 2.122 t ha^{-1} with high variation among major growing regions in the country (CSA, 2021). Farmers are obtaining less than 40% of yield potential of faba beans in the crop growing areas (Wondafrash *et al*., 2019). The high yield gap is due to low yielding variety, moisture and soil fertility, foliar disease, and weed infestation including the parasitic weeds serious infection.

Three parasitic weed species namely *Orobanche crenata* Forskal., *O. minor* Smith and *Phelipanche ramosa* (L.) Powel are reported attacking food legumes in Ethiopia (Asefa, 2007). These species are widely distributed in the world as a major constraint on cool-season food and forage legumes as well as other dicot plants (Restuccia *et al*., 2009). However, very recently two major crenate broomrape populations were found in samples collected from Amhara and Tigray Regions of the country (Gashaw *et al.*, 2020). Similarly, genetic variability and host differentiations of *O. crenata* is reported in north African countries like Algeria and Morocco (Mounia *et al*., 2017; Bendaoud *et al*., 2022).

The crenate broomrape (*O. crenata*) is believed to be introduced to few villages of northeast part of the country unintentionally along with food aid in the 1980's (Besufekad *et al*., 1999) and then gradually has expanded to different parts of the northern highlands (Teklay *et al.*, 2013; Negussie *et al.*, 2018). The parasitic weed is attacking majorly faba bean (*Vicia faba* L), and also field pea (*Pisum sativum* L.), lentil (*Lens culinaris* Medik), grass pea (*Lathyrus sativus* L.), lupin (*Lupinus* spp) and 'dekoko' (*P. sativum* var. *abyssinicum*) in the country (Takele *et al.*, 2019).

The dominance of crenate broomrape is recognized as a serious production threat on faba bean (Besufekad *et al*., 1999; Rezene and Kedir, 2006; Asefa, 2007; Teklay *et al.*, 2013; Mekonnen, 2016; Gashaw *et al.*, 2020). They further stated that the impacts include yield loss of up to 100% and make the straw unpalatable to livestock. In the South Wollo Zone, farmers abandoned cool-season food legumes, and replaced them with cereals and spice crops. They also indicated with the field surveys made over years that the parasite is expanding its geographic coverage from infested to the weed-free areas most probably due to seed exchange among farmers.

Rubiales and Fernandez-Aparicio (2012) reviewed all available innovations in managing parasitic weeds in legume crops including integrating different management options. Currently, in Ethiopia a faba bean variety called Hashengie (ILB-4358) as partial resistant to the parasite was released (MoANR, 2016). Some attempts were made to develop integrated management of the weed in faba bean using the partially resistant cultivar and one to two sprays of sub-lethal glyphosate (Mekonnen, 2016). Thus, some preliminary investigations indicated that the weed distribution and management practices were tried but detailed information was not documented from both regions in smallholder faba bean fields.

Documenting the distribution and infection status of crenate broomrape on faba bean enables to plan and execute further research, and to recommend suitable management practice to smallholder farmers. Many local field surveys were carried out in tracking the importance of crenate broomrape in the northern parts of the country (Besufekad *et al*., 1999; Teklay *et al.*, 2013), but there is no adequate and up to date information that show the current status of the weed and its importance in the county at large. Moreover, consistent weed monitoring is needed to manage the weed sustainably. Thus, the objective was to determine current distribution and infection level of crenate broomrape in faba bean fields of northern highlands of Ethiopia.

Survey Methodology

Survey area and time

The survey was conducted in major faba bean growing zones of northern Ethiopia; South Gondar, Southern Tigray and South Wollo (Fig. 1) in October and November of 2018. In each zone, by consulting respective offices of agriculture, faba bean production and orobanche infestation suspected districts were selected. Agro-ecologically the two zones were dominantly tepid sub-moist and cool sub-moist mid highlands (MoARD, 2006). Thirty years' mean annual rainfall and temperature status of the surveyed zones have been indicated in Table 1 (Fick and Hijmans, 2017).

Table 1. Long-term rainfall and temperature status of the surveyed zones in northern Ethiopia, 1970-2000

Status	Mean annual rainfall (mm)			Mean annual temperature (°C)		
	South Gondar	South Wollo	Southern Tigray	South Gondar	South Wollo	Southern Tigray
Minimum	755	625	505	7	6	9
Maximum	1539	1409	924	28	29	30
Mean	1166	1061	723	21	19	23

Source: Fick and Hijmans (2017)

Data collection and analysis

At the flowering stage of faba bean, its field surveys were inspected along all- and dry-weather roads at about five-kilometer intervals. At a stop, the faba bean field was sampled following "X" pattern, a 1m x 1m ($1m^2$) quadrate was used systematically at three to five spots per field, and number of faba bean plants and crenate broomrape shoots were counted and recorded. In addition, data on altitude, latitude and longitude were recorded using handheld Global Positioning System (GPS). Then, a total of 33 faba bean fields with 121 sampling spots were assessed.

The count data of crenate broomrape shoots per quadrate were categorized to different density levels; low (<10), medium (10-30) and high (>30), and then the number of fields under each density level described as frequency of occurrence. In addition, mean number of crenate broomrape shoots per faba bean plant calculated using the following formula (Rodenburg *et al.*, 2005).

$$\text{Infection severity} = \frac{\text{Count of crenate broomrape shoots per quadrat}}{\text{Count of faba bean stands per quadrat}}$$

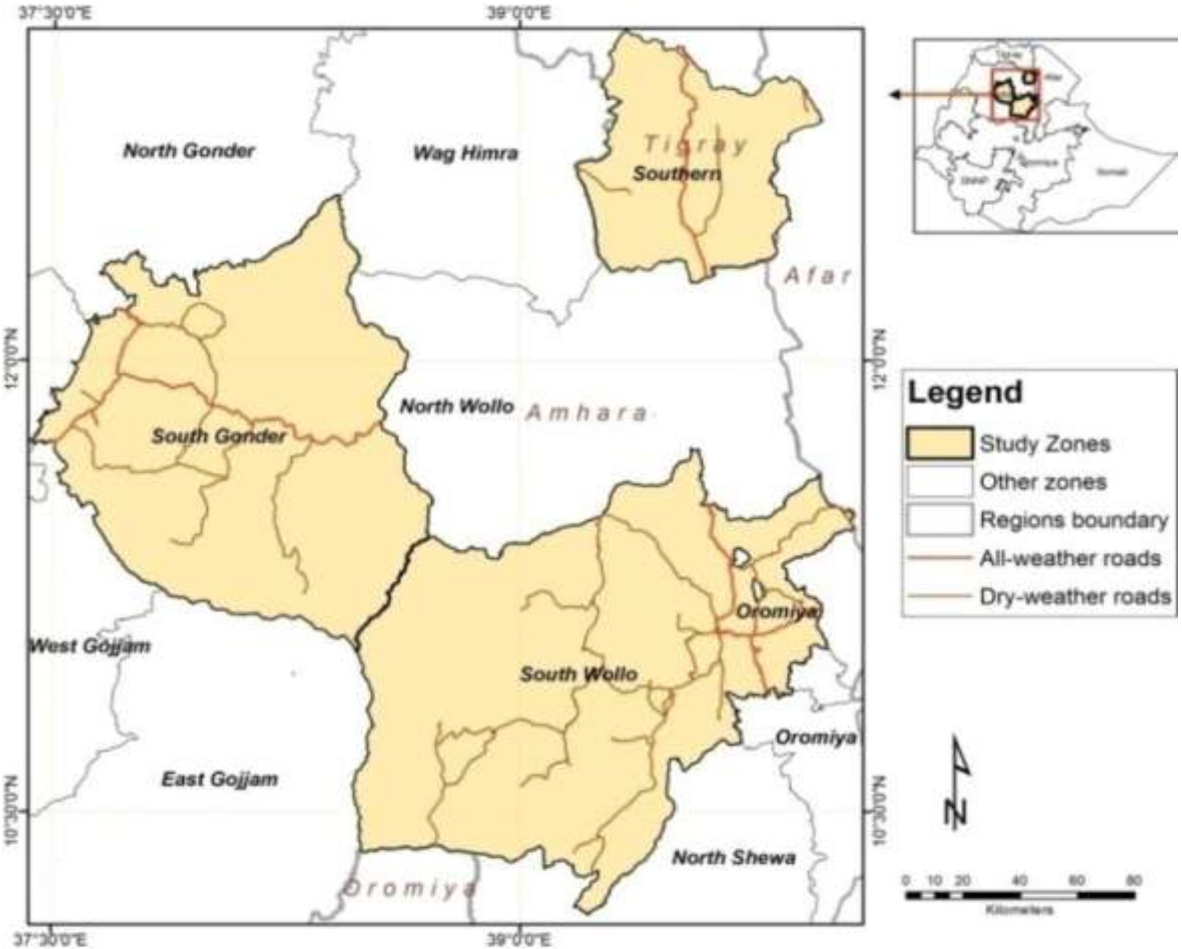

Figure 1. Surveyed zones of northern Ethiopia

The mean value represents severity of the parasite infection on the host plant i.e., infection severity at each sampling spot. The values enable to estimate mean number of emerged parasite shoots attached to roots of the host plant in each quadrate that were classified into low (0.01-0.09), medium (0.10-0.99), high (1.00-2.00) and very high (>2.00) shoots per host plant infection severity.

The on-field collected crenate broomrape density level and obtained infection severity data were analyzed using descriptive statistics, and SAS Version 9.3 (SAS, 2012) with nested design. Finally, these data have been independently plotted on the study area map showing status of the distribution and infection of crenate broomrape on faba bean plants under different agro-ecologies of the surveyed zones.

Results and Discussion

During the survey, small-holder faba bean growers' fields with typical light-brown soil located in wide ranges of altitude; 2200 to 3200 meter above sea level (m a.s.l.), latitude of 11^{o} 07' to 12^{o} 75' North and longitude of 38^{o} 46' to 39^{o} 52' East were visited.

Germination and growth performance of faba bean at the surveyed area

Mean faba bean plant density recorded ranged from 24 to 72 plants per square meter (m^{-2}). Non-significantly ($P>0.05$) higher mean density of 42 plants m^{-2} was obtained in the South Wollo Zone as compared to the other zones (Figure 2). Highly significant ($P \leq 0.01$) differences observed among the surveyed districts in the regions, where the highest mean faba bean density of 50 plants m^{-2} was recorded in Dessie-Zuria and Mekdela districts followed by Enda-Mahony district (40 plants m^{-2}) as compared to the other districts (Figure 3). These results indicated more suitability of the South Wollo Zone, and its districts particularly Dessie-Zuria and Mekdela district in cultivating the faba bean crop as compared to the other zones and districts in the studied area.

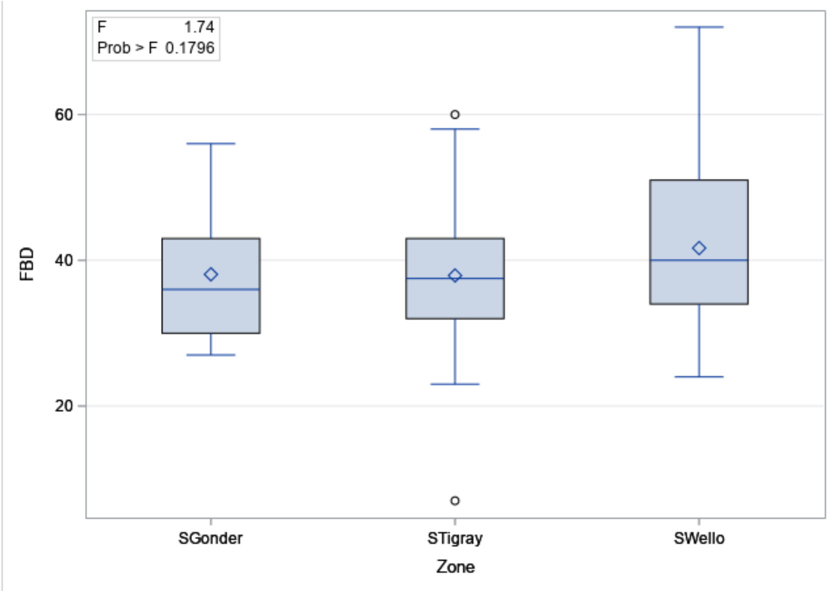

Figure 2. Mean faba bean density (FBD) across the studied zones, during 2018. Relatively highest density of 42 plants m^{-2} was recorded in South Wollo Zone as compared to the others.

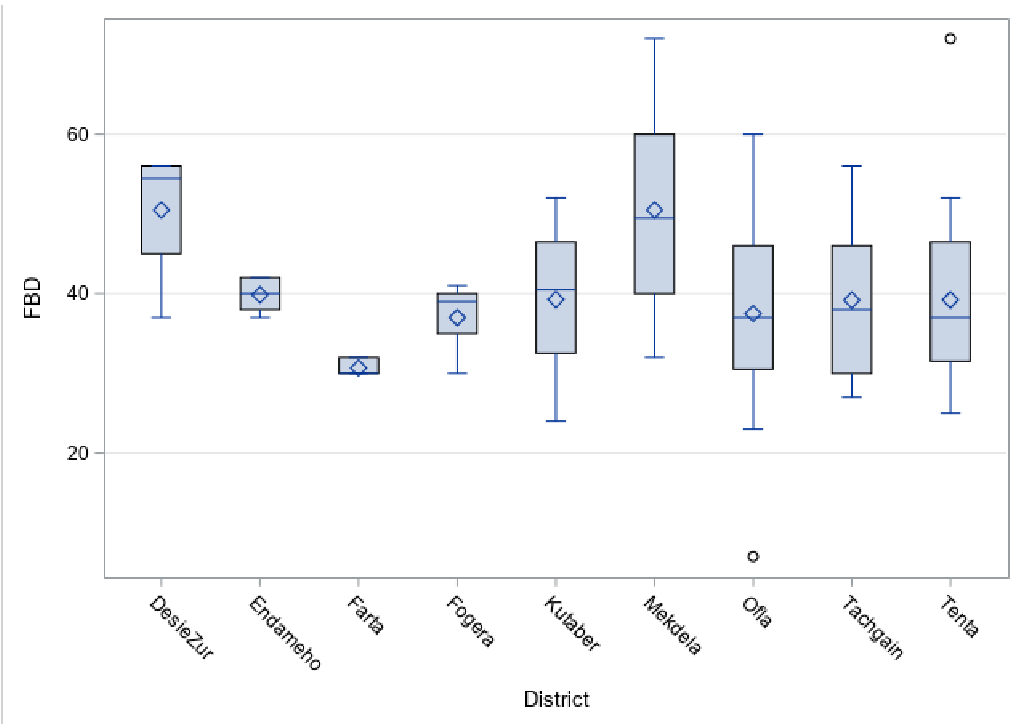

Figure 3. Mean faba bean density (FBD) across studied districts, during 2018. Significantly ($P < 0.05$) highest mean density of 50 plants m-2 was recorded in Dessie-Zuria and Mekdela districts than others.

Distribution of crenate broomrape

Crenate broomrape was recorded in faba bean fields of Amhara and Tigray National Regional States' districts. Those are Farta, Fogera and Tach-Gaint districts of South Gondar Zone; Dessie-Zuria, Kutaber, Mekdela and Tenta districts of South Wollo Zone, and Enda-Mahony and Ofla districts of Southern Tigray Zone. The prevalence of crenate broomrape in faba bean fields of South Wollo, South Gondar and Southern Tigray zones were found to be 96, 90 and 88%, respectively. Higher density levels of 134, 133, 117 and 105 shoots m^{-2} crenate broomrape were recorded from faba bean fields in Ofla, Tenta, Dessie-Zuria and Tach-Gaint districts, respectively. These districts might have been infested by the weed species earlier than other districts by two to three decades.

The recorded densities of crenate broomrape were grouped across the sampling spots as low (<10), medium (10-30) and high (>30) as indicated in Table 2 and on Figure 4. Higher mean density level of the crenate broomrape was detected more frequently in 15 and 10 fields in Tenta and Ofla districts than the other studied districts' faba bean fields. Similarly, Seid and Olivera (2016) reported density of the crenate broomrape ranging between 50 and 250 shoots m^{-2} in heavily infested districts, such as Mekdela and Tenta. The crenate broomrape mainly occurred on cool-season legumes and its infestation levels might have varied with different biophysical factors like seed bank and climatic conditions. Its occurrence was initially confined only to a few localities, but later on it has become a problem of many cool-season legumes growing in the northern part of Ethiopia, particularly in Amhara and Tigray National Regional States. Many research reports indicate the importance of crenate broomrape in the faba bean fields of the area (Besufekad *et al*., 1999; Teklay *et al.*, 2013).

Having ecological conditions suitable for such parasitic plant occurrence and infestation, Ethiopia reported as a crenate broomrape infested country many years later than the countries around the Mediterranean region. The crenate broomrape was reported for the first time in the country by Asefa and Endale (1994) as a new invader of faba bean fields in Dessie-Zuria and Kutaber districts of South Wollo Zone. Then after, Adugna *et al.* (1998) observed it infecting the same crop at Dera and Tach-Gaint districts of South Gondar Zone. Teklay *et al*. (2013) also reported the parasite infested districts of Southern Tigray Zone in Tigray Region. Similarly, Mekonnen (2016); Seid and Olivera (2016) indicated the weed infested districts such as Dessie-Zuria, Kutaber, Mekdela and Tenta in South Wollo Zone; and Tach-Gaint in South Gondar Zone of Amhara National Regional State. It has been spreading from place of introduction to other locations mainly through seed exchange among farmers, and also due to the fact that agricultural development agents and non-governmental organizations move farm inputs throughout the country without any restriction or domestic quarantine measures.

The current dense occurrence of crenate broomrape indicates that a huge number of seeds have been produced per a plant that can enrich soil seed banks by staying dormant for about two decades. Low atmospheric humidity ensures high rate of transpiration, which enhances movement of water and solute from host plants, so the weed plants' dense occurrence in the studied area might have been favored by this climatic condition besides the rich soil seed bank. Mohamed *et al.* (2006) reported that with increased temperature and drought due to climatic changes in many areas of the world, *Orobanche* species' dense infestation could pose greater threats to agriculture. Gevezova *et al*. (2012); Habimana *et al.* (2014) reported that a single crenate broomrape plant can set more than 500 000 minute seeds per season, which can easily disseminate over long distance by various mechanisms to weed-free neighboring fields, remain in soil viable for about 20 years and then heavily increase seed bank.

Analysis made on climatic requirement of *Orobanche* species suggested that very large areas of new territory of the world are at risk of invasion if no measure is taken to limit introduction of their seeds by strengthening quarantine Centre of a given weed-free country or region, and training agricultural experts and farmers to be alert on new infestations (Mohamed *et al.*, 2006; Grenz and Sauerborn, 2007). Crenate broomrape is a thermophilic plant that frequently requires dry conditions and light soils to be invasive (Negewo *et al*., 2022). These all issues hold true in the existing farming system condition of the northern highlands of Ethiopia.

Table 2. Number of faba bean fields with varying densities of crenate broomrape in the surveyed area

Region	Zone	District	Number of fields under various densities*		
			Low	Medium	High
Amhara	South Gondar	Tach-Gaint	17	9	3
		Fogera	9	0	0
		Farta	3	0	0
	South Wollo	Kutaber	2	6	4
		Dessie-Zuria	0	2	2
		Tenta	6	3	15
		Mekdela	3	1	2
Tigray	Southern Tigray	Ofla	9	9	10
		Enda-Mahony	6	0	0
Percentage			45	25	30

* Density level of low =<10, medium=10-30, high=>30 crenate broomrape shoots per m^2

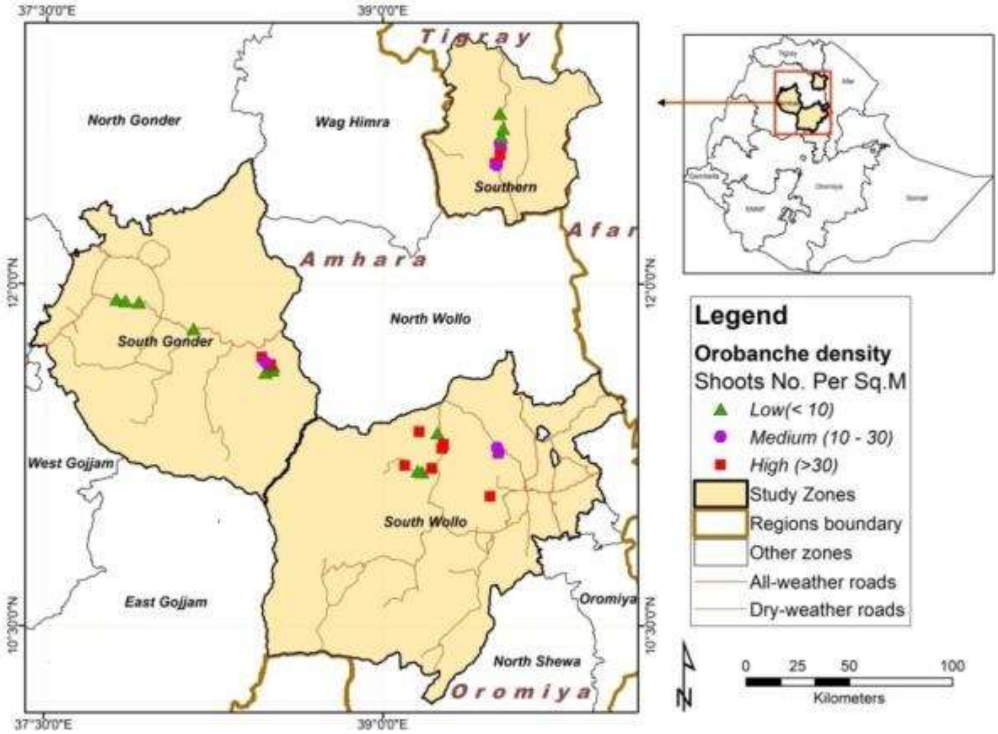

Figure 4. Mean density of crenate broomrape in faba bean fields of surveyed zones during 2018

Highly significant ($P \leq 0.01$) mean crenate broomrape density of 37 shoots m^{-2} was recorded in faba bean fields of South Wollo Zone as compared to South Gondar Zone that had only 12 shoots m^{-2} (Figure 5). Significantly ($P \leq 0.01$) highest mean crenate broomrape density levels of 60, 44 and 31 shoots m^{-2} were scored in Dessie-Zuria, Tenta and Ofla districts, respectively than the other districts (Figure 6). The highest infestation of crenate broomrape plants on such light soil dominated areas has been well expected. Thus, northern Ethiopia is currently found as an important area where crenate broomrape is a prevalent plant pest in legume crops particularly in faba bean fields. Frequent cultivation of the susceptible host crop (faba bean) seems the other main motive in aggravating spread of the crenate broomrape in the area. These limitations coupled with an ever-increasing population pressure that enhance ecological degradation and changes in climate conditions are further exacerbating the weed invasion year after year (Takele *et.al*., 2019).

Preventive measures could be effective and the most economical practices in reducing crenate broomrape infestation in agricultural fields. It is also important to consider the positive effects of cultural practices like crop rotation, intercropping, adjustment of seed sowing date and pattern, soil fertility management, and hand weeding. However, these practices were limited at large in the parasitic plant less densely infested crop fields (Kleifeld *et al*. 1994). Thus, the field survey density results need to be taken into account while planning site specific management measures on the crenata broomrape plant from the host crop fields.

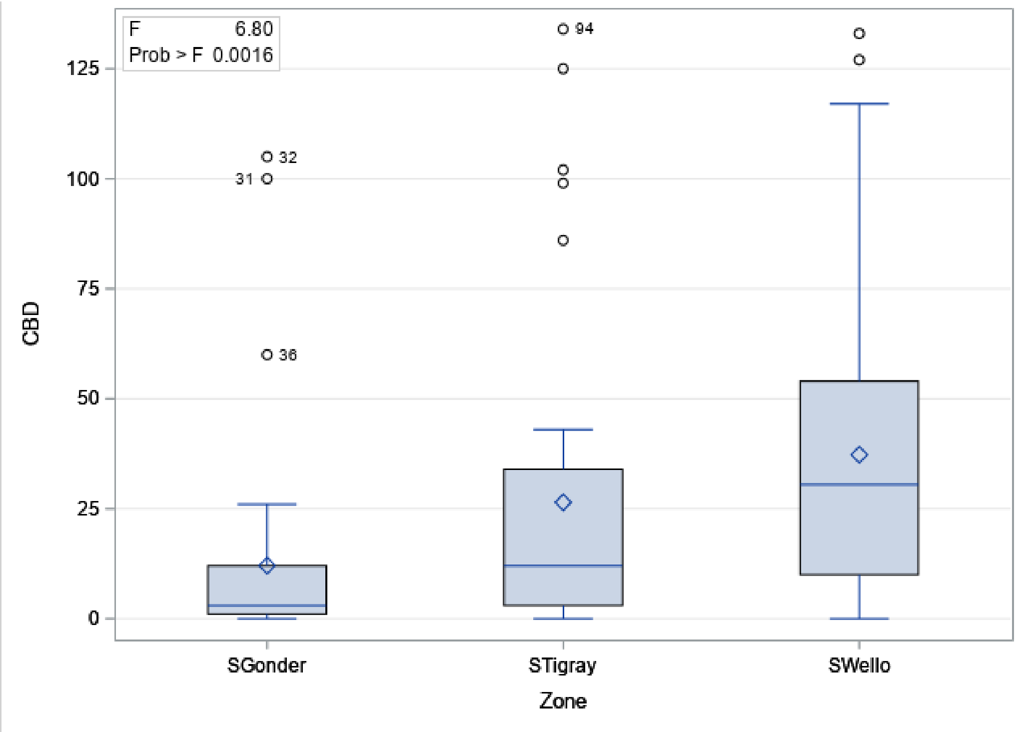

Figure 5. Mean crenate broomrape density (CBD) across the studied zones, 2018. Significantly (P < 0.01) highest mean density of 37 shoots m-2 was recorded in South Wollo Zone.

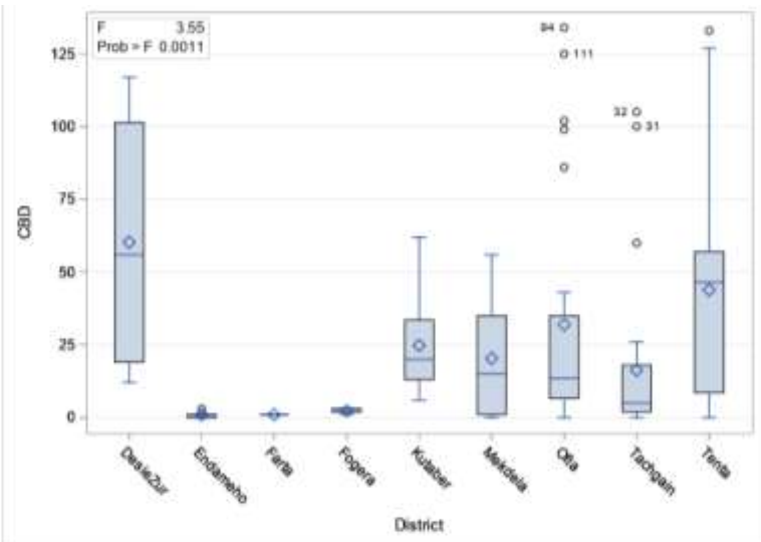

Figure 6. Mean crenate broomrape density (CBD) across the studied districts during 2018. Significantly (P < 0.01) highest mean densities were recorded in Dessie-Zuria, Tenta and Ofla districts than the others.

Infection severity of crenate broomrape

The crenate broomrape infection severity on faba beans showed considerable variation among the surveyed areas. Mean infection severities of the parasite on faba beans across the sampling spots were found ranging from low to very high (Table 3 and Figure 7). Higher infection severities of 14.14, 3.50, 3.45 and 3.16 crenate broomrape shoots per a faba bean plant were scored in Ofla, Tenta, Tach-Gaint and Dessie-Zuria districts, respectively. The mean infection severity of the crenate broomrape on faba bean across the sampling spots were grouped as low (0.01-0.09), medium (0.10-0.99), high (1.00-2.00) and very high (>2.00) parasite shoots per a crop plant. Higher levels of infection were more frequently (from about five faba bean fields) recorded in Tenta and Ofla districts than in the others.

Table 3. Number of fields with various infections of crenate broomrape on faba bean in the surveyed area

Region	Zone	District	Number of fields under various infections*			
			Low	Medium	High	Very high
Amhara	South Gondar	Tach-Gaint	13	13	0	3
		Fogera	9	0	0	0
		Farta	3	0	0	0
	South Wollo	Kutaber	0	10	2	0
		Dessie-Zuria	0	2	1	1
		Tenta	4	10	5	5
		Mekdela	3	2	1	0
Tigray	Southern Tigray	Ofla	3	18	2	5
		Enda-Mahony	6	0	0	0
	Percentage		34	45	9	12

* Infection severity of crenate broomrape shoots per a faba bean plant; low =0.01-0.09, medium=0.10-0.99, high=1.00-2.00, very high=>2.00

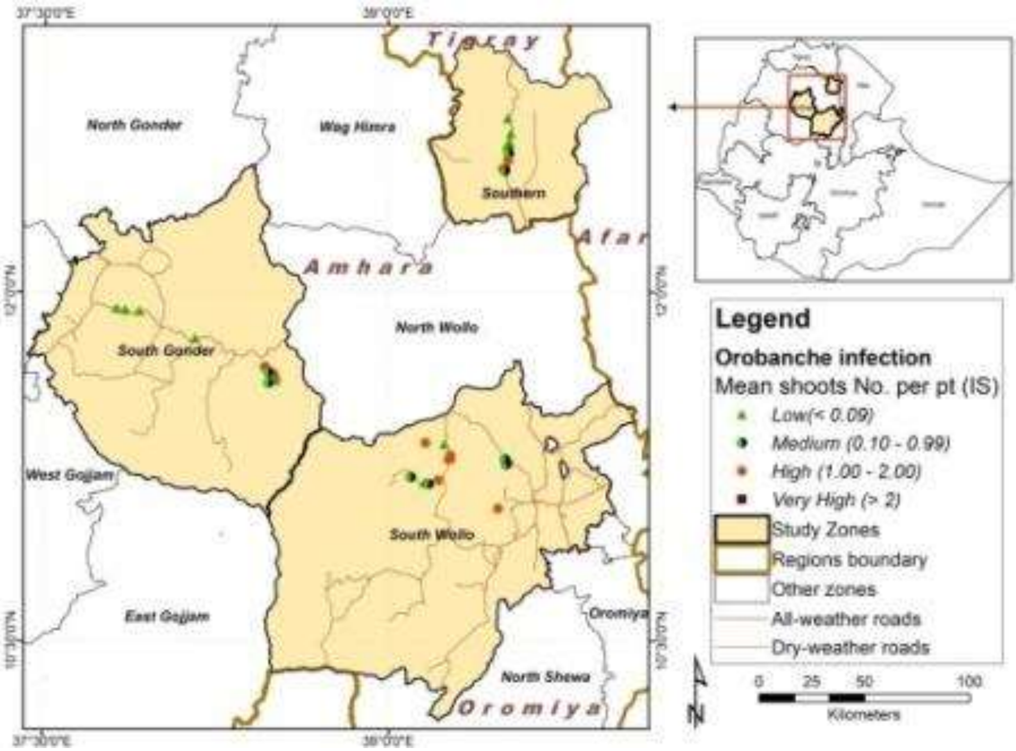

Figure 7. Mean infection severity of crenate broomrape on faba bean in surveyed zones during 2018

Crenate broomrape significantly ($P \leq 0.05$) higher mean infection severity of 1.07 shoots per faba bean plant observed in Southern Tigray Zone than South Gondar Zone (Figure 8). Significantly higher mean infection severity of 1.35, 1.29 and 1.15 scored respectively in Dessie-Zuria, Ofla and Tenta districts than Tach-Gaint and Fogera district (Figure 9). These districts also had the highest density of the faba bean crop and the crenate broomrape plants as indicated in the previous consecutive sections of this document. This strengthens the assumption that these districts had earlier infestation due to the parasitic plant than the other districts, even though more suitable for the crop plant cultivation. The possible reasons might also be due to continuous cultivation of the popular but susceptible host crop, moisture deficit and low soil fertility conditions in those districts.

Abandoning cultivation of faba bean by most farmers at the study area under such high infection of the parasite on the host crop seems reasonable or practical. Highly dense infection of the crenate broomrape induces acceleration of faba bean senescence, as a result the highly infected host plant dies earlier than the sparsely attacked one (Figure 10). Linke *et al*. (1991); Zaitoun *et al*. (1991) reported that the number of emerged *O. crenata* shoots are negatively correlated with productivity of infected faba bean plants. Infection severity of broomrape on the host crop is strongly related to different factors such as number of seeds in soil, and temperature and soil moisture conditions during the growing season (Manschadi *et al.*, 2001; Eizenberg *et al.*, 2005). Field orientation towards the afternoon sun, short time intervals while susceptible crop rotation, no irrigation and/or advancing of sowing date might also contribute to such a high level of crenate broomrape infection. Also, Trabelsi *et al.* (2017) reported that crenate broomrape dense infection tends to be associated with less fertile and moisture conditions of soil.

An increase of resources allocated within the crenate broomrape plant is concomitant to reduction of the host seed yield, indicating that the parasite growth and host reproduction compete directly for resources within a host plant. The vegetative growth and grain yield of faba bean was almost negligible at those fields with very high infection severities of the crenate broomrape. Previous studies also depicted that infection of 2.1 to 4.0 emerged crenate broomrape shoots per faba bean plant at harvest caused approximately a 50% reduction in the crop yield depending on the climatic conditions during the growing season (Mesa-Garcia and Garcia-Torres, 1984; Linke *et al.*, 1991). Likewise, Fernandez-Aparicio *et al.* (2016) reported that reductions in host aboveground biomass observed starting at low infection severity and half maximal inhibitory performance predicted at 4.5 parasites per faba bean plant.

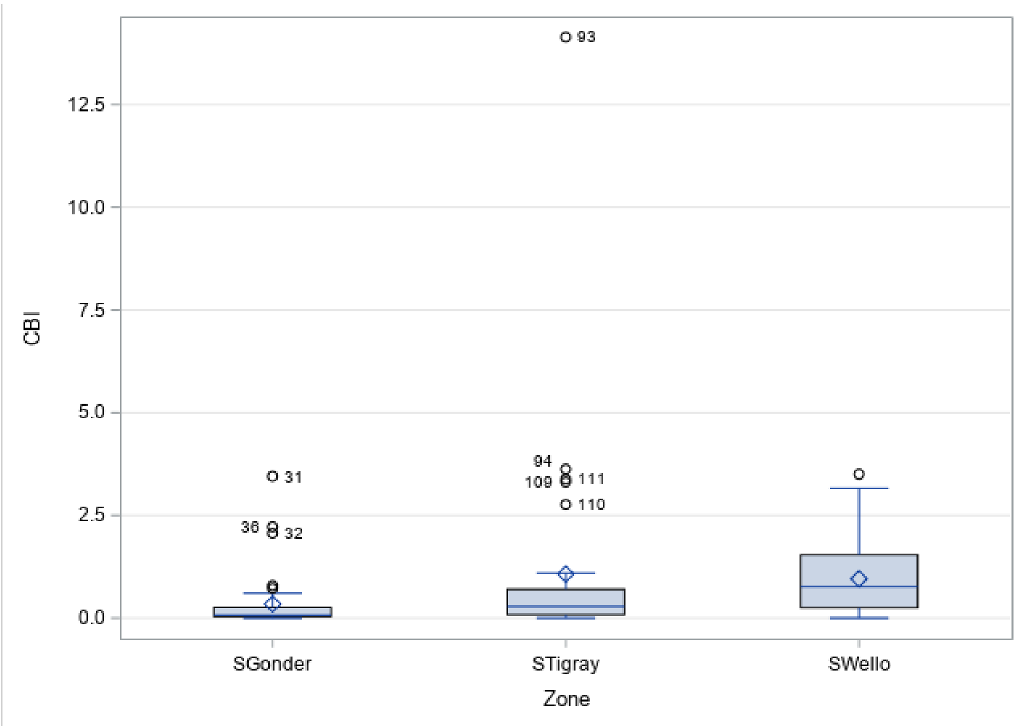

Figure 8. Mean crenate broomrape infection (CBI) on faba bean plant across the surveyed zones during 2018. Significantly ($P \leq 0.05$) higher mean infection severity of 1.07 parasite shoots per the crop plant was observed in Southern Tigray Zone than Southern Gondar Zone.

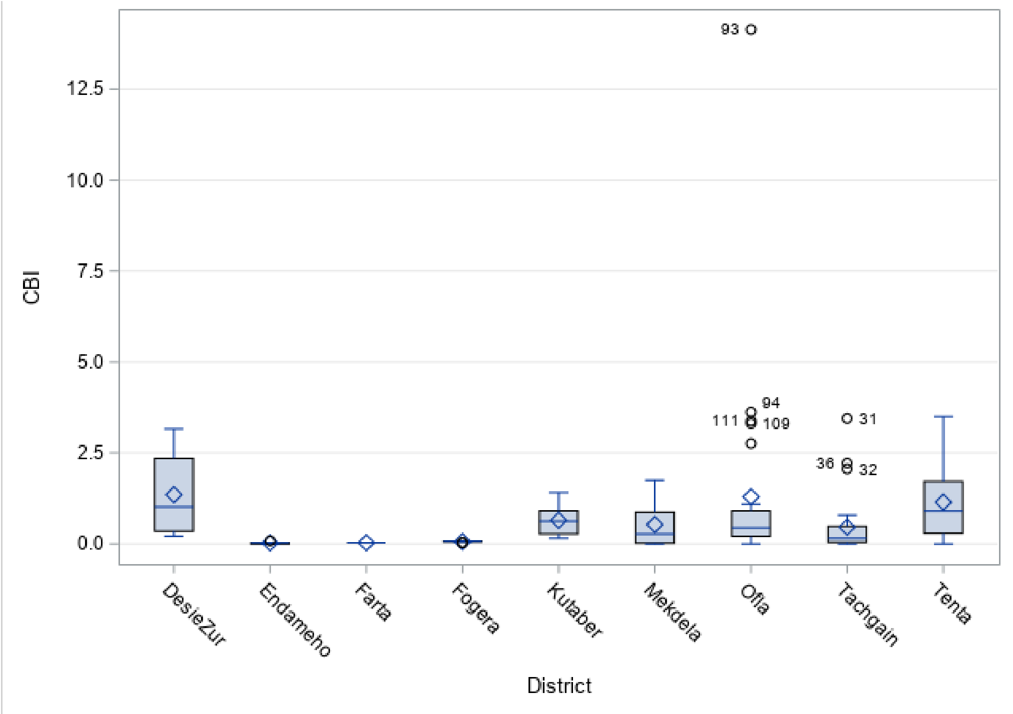

Figure 9. Mean crenate broomrape infection (CBI) on faba bean plant across the surveyed districts during 2018. Significantly ($P < 0.05$) highest mean infection severities were scored in Dessie-Zuria, Ofla and Tenta districts.

Figure 10. Crenate broomrape dense infection on faba bean in a farmer field of north Ethiopia

The crenate broomrape is a major biological constraint and also remained as continuous threat to cool-season legumes production in northern Ethiopia. In the highly affected area of North Wollo Zone, enormous growers stopped cultivating the crenate broomrape. As a result, substantial reductions in both the cultivated area and crop production occurred due to complete devastation caused by the weed (Seid and Olivera, 2016; Takele *et al.*, 2019). Thus, the high crop yield loss in the already infested area and the potential further expansion of the parasite to neighboring weed-free areas are the great concern of the country.

In the surveyed area, few growers cultivated faba beans with uncertainty just to obtain the crop grain that is much-desired for home consumption. As a result, fields planted with faba beans were very small in spite of the high concern of the farming communities to have cultivated the crop in the area. The current serious impact of crenate broomrape on specific host crops in the country might extend to other related crops in the future unless possible efforts are undertaken to restrict spread and invasion of the parasite. Moreover, it is noticed that the parasite impact on faba bean and field peas can be reduced when these host crops are intercropped with oat on infested fields, but can only be possible on soil with low seed bank condition (Fernandez-Aparicio *et al.,* 2013). Thus, the survey results of crenata broomrape plant infection severity on the host crop also need to be taken into account while planning site specific management measures.

Agricultural experts and elders in the surveyed area testified an increase in the number of crenate broomrape infested fields and occurrence of dense infection in cool-season legumes. Lack of preventive measures and awareness on biology of the parasite might have contributed to such wide distribution and an ever-increasing infection level on the host crop across the studied area. Likewise, Bulbul *et al*. (2009) reported that lack of effective countermeasure against broomrape is contributing to the continuously increasing importance of the weed species in agricultural areas. Hence, the spread of the crenate broomrape has escalated at an alarming speed putting all food legumes at jeopardy and then limitation on such valuable rotational crops indirectly lowering the productivity of cereals mono-cropped production system as reported by Teklay *et al.* (2013). Furthermore, the difficulty in containing crenate broomrape distribution in the study area is also assisting its expansion to weed-free neighboring locations including central and southern part of the country.

Conclusion

Crenate broomrape infestation in faba bean fields was recorded in nine districts of three zones in the northern highlands of Ethiopia; Amhara and Tigray National Regional States. Considerably high density and infection by the crenate broomrape were recorded in Ofla, Tenta and Dessie-Zuria districts. The crenate broomrape dense occurrence in the already infested area and further spread to the weed-free neighboring areas are of great concern in the country. Strict domestic quarantine, proper field sanitation and awareness creation among the farming communities on the biology of the weed at grass root level need to be implemented to restrict the dense infestation and further spread of crenate broomrape. Proper cropping systems and farm practices like growing resistant and/or tolerant faba bean cultivars, crop rotation systems with long time intervals between successive susceptible crops, intercropping with catch or trap crops, soil inoculation with beneficial microbes, spraying of selective herbicides, conservation of an ecology and development of integrated management strategy are mandatory to come up with reduced problem of the crenate broomrape. Thus, farmers at the parasitic weed infested area and also the weed-free neighboring areas of the country need to be advised and aware with technology and information that enable them limiting the buildup of soil seed bank and further expansion of crenate broomrape inoculum in faba bean production fields.

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Declaration of interest statement

The authors express that there is no competing interest to declare.

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