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Performance of faba bean (*Vicia faba* L.) varieties grown under broomrape (*Orobanche* spp.) infestation in South Tigray, Ethiopia

Lemma Diriba[1*], Firew Mekbib[2] and Mussa Jarso[1]

[1]Ethiopian Institute of Agricultural Research Center, Ethiopia.
[2]Department of Plant Sciences, Faculty of Agriculture and Environmental sciences, Haramaya University, Ethiopia.

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Broomrapes (*Orobanche* spp.) are the serious roots parasitic weed to legumes crop production in many countries. In Ethiopia, *Orobanche crenata* is a dominant parasite and a major constraint to faba bean (*Vicia faba* L.) cultivation, especially in the Northern parts of the country. Presently, it reduces crop production and has forced farmers to stop growing faba bean crop. Thus, it is necessary to find new sources of resistance, understand means of resistance mechanisms to facilitate faba bean resistance breeding, and identify the best performed with high yielding variety to sustain their production and productivity. Thus, to evaluate the performance and their degree of resistance, twenty faba bean varieties were tested under the area affected by Orobanche infestation, at Korem experimental site of Alamata Agricultural Research Center, Tigray, Ethiopia during 2017 cropping season by using Randomized Complete Block Design (RCBD). All difference among faba bean varieties was analyzed using Tukey's Standardized Range (P ≤ 5%) Test. Higher level of broomrape infection was observed during host-pod setting stage. During evaluation, 13 out of 20 tested faba bean varieties were the superior yielding varieties (312.5 - 3129.17 kg ha^{-1}), whereas the remaining seven varieties completely lost yield due to 100% Orobanche infestation. Cluster analysis was then carried out and the varieties were grouped into different clusters with different sizes based on their level of resistance or susceptibility. Three varieties 'Ashenge, Dedia and Obse' were selected for their best performance. Accordingly, Ashenge variety was selected as partially resistant with highest yield provided due to lowest occurrence of Orobanche infestation within variety. Future breeding program therefore, should mainly focus on these three selected varieties to improve the problem of faba bean production by using conventional and molecular breeding methods.

Key words: *Orobanche* spp., *Vicia faba*, resistance/tolerance.

INTRODUCTION

Faba bean (*Vicia faba* L.) is one of the earliest domesticated food legumes in the world (Singh et al., 2013) that is grown under rain fed and irrigated conditions in many countries. It has high nutritional value

*Corresponding author: E-mail: lemmadiriba@gmail.com.

and is used almost daily in human diet of many Ethiopians (Teklay et al., 2015). Due to its high nutritional value and its ability to grow over a wide range of climatic and soil conditions (Yahia et al., 2012), faba bean is the fourth most important legume worldwide after pea, chickpea and lentil. It is grown under different cropping systems as dry grains, green pods, animal feed and green-manure in the world. The main faba bean producers are China (2.1 Mt), Ethiopia (0.8 Mt), France (0.65 Mt), Egypt (0.4 Mt) and Australia (0.25 Mt) (FAOSTAT, 2016).

Faba beans require a cool season for best growth with moderate amounts of rainfall 650 to 1000 mm per annum (Gasim and Link, 2007), considered to tolerate frost, but are susceptible to drought and water logging (Subash and Priya, 2012). Faba beans are moderately tolerant to acid soil conditions than most legumes (Singh et al., 2010) and can tolerate a wide range of soil types with pH 6.5 to 8.0 (Rajan et al., 2012), but grow best in loamy soils. The crop takes about four or five months for the pods to mature enough for the seeds to be harvested based on environmental condition (Mussa et al., 2008). In Ethiopia, the major faba bean producing regions are Oromia (Wollega, Shoa, Bale), Amhara (Gondar, Gojam, Wollo), Southern parts of the country (Gamo Gofa), Benishangul-Gumuz and highland parts of Tigray (CSA, 2016/2017).

However, there are different biotic (diseases, insect pests, and parasite weeds) and abiotic (drought, salinity, fertility etc.) constraints that limit the production and productivity of the faba bean (Mussa et al., 2008). Recently, in addition to the previous common diseases such as chocolate spot, faba bean rust, aschochyta blight, virus, nematode, etc., the crop is threatened by new gall forming disease which become a very dangerous problem that is seriously affecting faba bean production (Dereje et al., 2012). This new disease mainly affects the leaves and stems with typical symptoms of green and sunken on the upper side of the leaf, bulges to the back side of the leaf and then develops light brownish color lesion and chlorotic galls (Hailu et al., 2014). It is the most destructive disease that causes yield loss up to 30-100%. Broomrapes (Orobanche spp.) remain one of the constraints of faba bean production that is known by the aggressive root parasitic weeds and are completely dependent on the host due to the lack of chlorophyll and functional roots (true roots) (Eizenberg et al., 2010).

Legumes are parasitized mainly by two different species of broomrapes, namely crenate broomrape (*Orobanche crenata* Forsk.) and foetida broomrape (*Orobanche foetida* Poir) (Rubiales, 2014). Although other Orobanche species can infect leguminous plants, they are generally of little economic importance. *O. crenata*, however, has a wide host range among legumes crop in temperate climates. It was known in the past as an agricultural weed in Europe, but currently it is not common as such any more. It is found in native and disturbed habitats throughout the central and southern parts of Europe, and extends to the eastern coast of Africa and southwards. In addition, it was imported to various other parts of the world and is currently found as a garden weed. *Crenate broomrape* (*O. crenata* F.) is the most damaging, widespread, and most dominant parasite compared to foetida broomrape (Fernández et al., 2012). The damage caused by this parasite on faba bean crop is significant and estimated yield losses is about 7 to 80% depending on the level of infestation (Maalouf et al., 2011).

Broomrapes have a single stem and can release more than 100,000 seeds that are known to remain viable for decades in the soil (Eizenberg et al., 2010). This provides the parasite with a great genetic adaptability to environmental changes, including host resistance, agronomical practices and herbicide treatments. Orobanche spp. parasitizes a number of crops globally, with legumes being some of the most severely damaged, and only germinates in response to specific chemicals released by the host plant (germination stimulant compound present in the root exudate). However, before being able to respond to this external stimulus, the seeds need to be exposed to moist conditions at a suitable temperature (optimum 15-20°C) for a certain period of time. Following germination, the seedlings attach to the host roots and grow at the expense of the host plant's resources (Joel et al., 2007). As they are root parasitic weeds, most of their infection and pathogenesis process take place underground, which complicates diagnosis of infection and control (Rubiales et al., 2009). This continuing invasion of Orobanche is exacerbated (worsened) by the lack of knowledge of the farmers and the official agricultural experts, about the biology and exact means of spread of this parasite and un-sufficient availability of breeding for Orobanche resistance faba bean varieties.

The particular characteristics (underground development, attachment to the host roots) of this pathogenic weed hamper the development of effective control strategies. A number of methods for controlling broomrape in faba bean are practiced, including agronomical practices (like intercropping, fertilizer application) and chemical treatments (application of glyphosate at low rates) (Rubiales et al., 2016; Eizenberg et al., 2010). Because of the extreme difficulty of controlling broomrape, prevention is most importance. Traditionally, the sources of infection can be reduced by controlling the use of contaminated seed lots, farmyard manure from broomrape fed cattle, and hand weeding. However, the most desirable control strategy is the use of tolerant or resistant cultivars. Moreover, the levels of resistance available in faba bean cultivars are low and of narrow genetic basis in spite of the many efforts made by national and international programs. Resistance against broomrape is a particularly difficult character to assess as it is highly influenced by environmental factors (Rubiales et al., 2016).

In Ethiopia, the Orobanche infestations become quickly distributed over large area of cultivating lands. Northern parts of the country, especially Gonder, southern and western part of Wollo and southern Tigray were the most dominated area by this parasite. The estimated yield losses in faba bean due to *O. crenata* is as high as 75 to 100% yield loss depending on host susceptibility, level of infestation and environmental conditions (Teklay et al., 2013).

Heavy Orobanche infestation does not only lead to a complete crop failure, but make soils Orobanche-sick over a long period of time. Because of unidentifiable nature and difficulty of parasite to the farmers, the only option they took is, planting other cereal crops instead of faba bean, which are not affected by this parasite weed. However, this practice leads to a decrease in the progress of faba bean production and productivity thoroughly. Presently, the continuous spread of Orobanche limits the choice of rotational crops and often force farmers to stop growing this most valuable crop (Teklay et al., 2013). Thus, in Ethiopia, particularly the northern part, productivity of the crop is decreasing due to the infestation of this parasite weed. Hence, there is a need to evaluate faba bean performance with high yielding varieties to find new sources of resistance, and to understand the underlying resistance mechanisms in order to facilitate faba bean resistance breeding. Therefore, the main objective of this study is to evaluate the performance of faba bean varieties for resistance against broomrape species.

MATERIALS AND METHODS

Experimental materials

Twenty faba bean varieties were obtained from different Agricultural Research Centers in Ethiopia as listed in Table 1. One standard check (as resistance control) was obtained from Alamata Agricultural Research Center. The selection of these varieties was based on their productivity and high productive faba bean varieties across different agro-ecologies were selected. All of the varieties were evaluated for their response to the parasites in highly infested field with *Orobanche* spp.

Description of the study area

The experiment was conducted at Korem districts of South Tigray Zone, located at 12°31'N latitude and 39°33'E longitude, at research station of Alamata Agricultural Research Center (AARC) during the main cropping season of 2017. The area represents highlands of South Tigray Zone with moderate rainfall (average annual rainfall of 600 mm), which extends mostly from half of June to late September, with a dominant soil type (clay) and slightly acidic with a pH of 6.4 (Teklay et al., 2013).

Experimental design and management

This experiment was evaluated using Randomized Complete Block Design (RCBD) with three replications. The space between replication was 1.5 m. Each plot consists of 4 rows of 3 m length, with 0.1 and 0.4 m intra and inter row spacing respectively (3 m × 1.6 m = 4.8 m² plot size). At planting, 100 kg ha^{-1} DAP was applied. All the culture practices were applied during the growing to ensure good crop stands. Hand weeding, other than broomrape was done. However, herbicide was not applied to avoid interference with broomrape development.

Data collection

Data collection from plot and plant bases

Days to 50% emergence, stand count after emergence, days to 50% flowering, plant height (cm), days to 90% maturity: stand count at maturity, 100-seed weight after being adjusted to 11.6% moisture content, yield per hectar (kg), biomass (kg), harvest index (HI) = $\left(\frac{Grain\ yield}{Total\ biomass\ yield}\right) \times 100$, number of nodes per plan, number of pods per node, number of pods per plant, pod length (cm), and number of seeds per pod were the data collected during the experiment. All data were recorded from five plants randomly selected from the two middle rows and computed for their mean value.

Data on broomrapes infestation

Number of *Orobanche* shoots per plot: The total number of broomrapes grown per plot was recorded at three host growing stages (flowering, pod setting and maturity) and calculated for their average values.

Number of *Orobanche* per plant: Number of *Orobanche* spp. grown per single plant was recorded from five randomly selected plants at three host growing stages (flowering, pod setting and maturity) and computed for their mean values.

***Orobanche* incidence (%):** Percentage of faba bean plants hosting *Orobanche* shoots per plot was measured. This implies that, first the percentage of host plant that persist with having yield under *Orobanche* infestation was measured, then subtracted from hundred to gain the percentage of *Orobanche* incidence.

Data analyses

All collected data were subjected to ANOVA (one way ANOVA) using SAS version 9.2. Simple descriptive statistics (such as means and coefficient of variation) was used in order to compare variation between varieties or traits. The significance of the mean difference between varieties was evaluated by the Tukey's Standardized Range (HSD) Test at P ≤ 0.05.

Principal component analysis (PCA)

Principal component analysis was used for multivariate analysis after the means of all traits were computed and properly arranged, and for grouping faba bean varieties into different groups based on their response to the level of *Orobanche* infection.

Cluster analysis

Cluster analysis was carried out for tested traits and grouping of twenty faba bean varieties into different clusters based on their degree of resistance. All analyses were conducted using SAS

Table 1. Description of faba bean Varieties used for the study.

S/N	Name of varieties	Maintainer	Year of release
1	Holetta-2 (BP 1802-1-2	HARC	2001
2	Selele (Selele kasim 91-13)	HARC	2002
3	Wayu (Wayu 89-5)	HARC	2002
4	Moti (EH 95078-6)	HARC	2006
5	Gabelecho (EH96009-1)	HARC	2006
6	Obse (EH 95073-1)	HARC	2007
7	Welki (ETH 96049-2)	KARC	2008
8	Dosha (Coll 155/00-3)	HARC	2009
9	Mesay	HARC	1995
10	Tumsa (EH-99051-3)	HARC	2010
11	Hachalu (EH009102-4-1)	HARC	2010
12	Bulga-70	HARC	1994
13	Degaga	HARC	2002
14	Didea	HARC	2014
15	Tesfa	HARC	1995
16	Gachena (ETH 91001-13-2)	HU	2008
17	Ashenge (Resistant)- check	Alemata ARC	2014
18	Mosisea (EH-99047-1)	Sinana ARC	2013
19	Aloshe	Sinana ARC	2017
20	Shallo	Sinana ARC	2000

statistical software version 9.2.

RESULTS AND DISCUSSION

Days to 50% flowering

Analysis of variance showed that there was highly significant difference ($P \leq 0.01$) among faba bean varieties in days to 50% flowering (Table 2). The varieties Moti, Ashenge and Mosise flowered early within 46.67, 46.67 and 47.33 days, respectively, whereas Hachalu variety (56 days) was the latest, followed by Dosha and Tumsa varieties (54 days). At flowering stage, there were a few number of *Orobanche* emergence per plant. Thus, the result of this study showed that days to 50% flowering were not much influenced by *Orobanche* infestation even if the variation observed was due to genetic character of the varieties (Table 3).

Days to 90% maturity

The mean for days to maturity for tested varieties ranged from 114 days to 122 days, which was found to be highly significantly different ($P \leq 0.01$) (Table 2). The varieties that were highly affected by *Orobanche* infestation or susceptible and highly susceptible varieties were pushed to mature early which take days to 90% maturity ranging from 114 to 119. Concerning the mean value of the crops' life cycle, significantly higher days to 90% maturity was observed in partially resistant and tolerant varieties such as Ashenge (122.33), Obse (122), and Dedia and Mosise (120.67) (Table 3), which showed that these varieties kept their optimum days to maturity, and might be due to their high defense mechanisms and ability to tolerate the parasite. This result indicated that maturity date was affected by *Orobanche* infection. Rubiales (2014) also reported similar result.

Plant height

There were highly significant variations among tested faba bean varieties ($P \leq 0.01$) in plant height which was influenced by *Orobanche* infestation and varieties' character. The maximum plant height was recorded from Ashenge, Dedia, Gachena and Degaga varieties with height of 78-90 cm, whereas, the shortest plant heights were recorded from Tesfa, Wayu and Gebelcho varieties with height of 51.9 - 55.47 cm (Table 3). The result of this investigation revealed that *Orobanche* infestation had significant effect on plant growth by reducing the height of the plants.

Number of nods per plant

The influence of broomrapes in addition to varieties' genetic variability did exert highly significant variation ($P \leq 0.01$) on number of nods per plant (Table 4).

Table 2. Level of significance for phenological traits from analysis of variance for faba bean varieties grown under broomrapes.

Character/trait	Mean square		Mean	R^2
	Varieties (*df =19*)	Error (*df = 38*)		
Stand count after emergence	10.3^{NS}	11.45	48.22	0.47
Number of plant harvested with yield	202.42**	0.74	8.48	0.99
Days to 50% flowering	21.9**	0.36	50.33	0.97
Days to maturity	21.9**	1.20	117.6	0.90
Plant height	283.36**	28.85	66.87	0.83
Number of *Orobanche* per plot	3417.65**	108.6	77.7	0.98
Number of *Orobanche* per plant	3.59**	0.25	3.05	0.97

** =highly significant ($P < 0.01$), NS = none significant, df = degree of freedom and R^2 = coefficient of determination.

Table 3. Combined mean of *Orobanche* emerged plot^{-1} and plant^{-1} (at three host-growing stages) and its effects on faba bean varieties for phenological traits.

Variety	Mean of *O.* emerged at three host growth stage		OI (%)	DF 50%	DM 90%	NNP	PH
	NOPP	NOPT					
Holleta-2	73.3^{fgh}	3^{cd}	76^{cd}	49^{d}	115^{fg}	6^{ab}	67.5^{bcd}
Salale	70.4^{fgh}	2.76^{cd}	66.69^{g}	49.33^{d}	116.33^{def}	5^{bc}	67.6^{bcd}
Wayu	61^{h}i	2.95^{cd}	72.76^{def}	53^{bc}	118^{bcd}	6.33^{ab}	55.33^{ef}
Moti	84.56^{cde}	3.9^{ab}	100^{a}	46.67^{f}	114^{g}	4.33^{c}	69^{bcd}
Gebalcho	75.2^{ef}	3.2^{bcd}	100^{a}	49.33^{d}	115^{fg}	5.33^{bc}	51.97^{f}
Obse	67.67^{fgh}	3.2^{bcd}	57.15^{h}	48^{def}	122^{a}	5.33^{bc}	70.4^{bcd}
Welki	78.2^{def}	2.78^{cd}	81.9^{b}	52^{c}	116.33^{def}	5.33^{bc}	66.33^{cde}
Dosha	92.67^{bcd}	2.69^{cd}	100^{a}	54^{b}	120.67^{ab}	4^{c}	65^{cde}
Mesay	43ij	2.4^{d}	73.72^{de}	53^{bc}	118.67^{bc}	6.33^{ab}	62.17^{def}
Tumsa	95.67^{bc}	4.3^{a}	100^{a}	54^{b}	114^{g}	5.33^{bc}	60.33^{ef}
Hachalu	77^{ef}	3.18^{bcd}	100^{a}	56^{a}	118.67^{bc}	5.33^{bc}	58.6^{ef}
Bulga-70	79.56^{def}	2.64^{cd}	74.6^{de}	49.33^{d}	118.67^{bc}	5.33^{bc}	64.8^{cde}
Degaga	70.56^{fgh}	3^{b}	68.36^{fg}	49^{d}	115^{fg}	6.33^{ab}	78^{abc}
Dedia	79.78^{def}	2.89^{cd}	54.24^{h}	48.67^{de}	120.67^{ab}	6.33^{ab}	80.3^{ab}
Tesfa	118.1^{a}	4.2^{a}	100^{a}	48^{def}	115.33^{ef}	5.33^{bc}	55.47^{ef}
Gachana	104.2^{ab}	3.27^{bcd}	70.77^{efg}	49.33^{d}	119^{abc}	7^{a}	79.5^{ab}
Ashange	33j	1.5^{e}	38.5i	46.67^{f}	122.33^{a}	7.33^{a}	90^{a}
Mosise	85.44^{cde}	2.6^{d}	79.16^{bc}	47.33^{ef}	120.67^{ab}	6^{ab}	74.33^{bcd}
Aloshe	98^{bc}	3.49^{abc}	100^{a}	52^{c}	116.67^{def}	4^{c}	58.4^{ef}
Shalo	65.89^{gh}	2.69^{cd}	82.78^{b}	52^{c}	114.33^{g}	5.33^{bc}	62.33^{def}
CV (%)	13.41	16.43	1.9	1.20	0.93	11.36	8.03

NOPP = Number of *Orobanche* per plot, NOPT = number of *Orobanche* per plant, OI=*Orobanche* incidence, DF = Days to 50% flowering, DM = Days to maturity, NNP = Number of nods per plant, PH = Plant height and CV = Coefficient of variation. Means with the same letter per column are not significantly different.

Significantly higher number of nods plant^{-1} (7) was observed on variety Ashenge (resistance control) and Gachena, followed by Dedia, Degaga, Wayu, Messay and Mosissie (6); whereas, significantly lower number of nods (4) was observed on Dosha and Aloshe varieties. The number of pods borne on each nods was varied and variety dependent ranging from 0 to 1.7 pods per nod (Table 5).

Number of pods per plant

Number of pods per plants was highly ($P \leq 0.01$) affected by broomrapes and faba bean varieties (Table 4). The

Table 4. Level of significance for yield and yield related traits from analysis of variance (ANOVA) for tested faba bean varieties grown under broomrapes at Alemata Agricultural Research Center (Korem) experimental site.

Character/trait	**Source of variation**		**Mean**	**R^2**
	Varieties (*df =19*)	**Error(*df = 38*)**		
Number nods per plant	2.38**	0.47	5.6	0.73
Number of pods per plant	62.29**	0.26	5.78	0.99
Number of seeds per pod	7.29**	0.01	1.94	0.99
Pod length	29.17**	0.2	3.8	0.99
Hundred seed weight	7229**	1.57	37.33	0.99
Grain yield in kg ha^{-1}	1814121.5**	675.18	595.7	0.99
Biomass yield in kg ha^{-1}	5105394**	68716.97	3064.2	0.97
Harvest index	640.78**	0.5	14.9	0.99
Number of *Orobanche* per plot	3417.65**	108.6	77.7	0.98
Number of *Orobanche* per plant	3.59**	0.25	3.05	0.97

** =highly significant ($P < 0.01$), NS = none significant, df = degree of freedom and R^2 = coefficient of determination.

number of pods available on a plant depends on number of nods per plant and pod produced on each nod. Highest number of pods per plant was recorded from varieties Ashenge (control) (11.67) and Dedia (11.3), followed by Degaga and Wayu with 10 and 9.3, respectively. The result of this finding showed that only 13 varieties performed with pod setting out of 20 tested varieties with different values in pods number ranging from 7 (Mosissie) to 11.67 (Ashenge), whereas the other seven varieties did not set any pod due to their high susceptibility to *Orobanche* infestation and scored zero (Table 5). However, according to Ashenafi and Mekuria (2015) and Teama et al. (2017), about 10-15 pods per plant were produced from these susceptible varieties under non *Orobanche* infestation area.

Number of seeds per pod

The number of seeds obtained from pods was dependent on the performance of faba bean varieties established under *Orobanche* infestation. The highest seed per pod was obtained from partially resistant and tolerant varieties. Accordingly, the maximum value of seeds from single pod was recorded from variety Ashenge/resistance control as well as Gachena (4.00) and Obse (3.8), while the minimum number of seeds was recorded from Shalo, Welki and Bulga-70 with the value of 2.00 seeds per pod, excluding highly susceptible varieties that had scored zero values (Table 5). However, the varieties with lowest seed per pod in this study were highly productive under non-*Orobanche* infestation area, as indicated in the finding of Ashenafi and Mekuria (2015) at Sinana and Agarfa districts of Bale Zone; whereas Welki, Shallo, Hachalu, Tumsa, Gebelcho, Dosha, Moti and Mosise varieties produced about 3.2 to 4.3 seeds pod^{-1}. This implies that *Orobanche* infection causes yield reduction by 95-100% in susceptible varieties.

Pod length

Orobanche infestation and varieties' genetic variability exerted significant effect on pod length. Also, there were highly significant variations ($P \leq 0.01$) in pod length among tested faba bean varieties (Table 4). The highest pod length was recorded from varieties Gachena (8.67 cm), Obse (8.33 cm) and Ashenge (7.33 cm) followed by Dedia (6.67 cm) variety. Without considering susceptible varieties, which scored zero values, the minimum value of pod length was recorded from Welki and Bulga-70 varieties with 4 cm length (Table 5).

Hundred-seed weight

In addition to genetic character of faba bean varieties, the level of *Orobanche* infestation did exert significant effect on 100 seed weight ($P \leq 0.01$) (Table 4). In some varieties, hundred seed weight depended on seed size, in which largest seeds gave higher values of weight. Unfortunately, of those varieties performed with yield, a susceptible 'Gachena' variety produced heaviest seed weight (83.67 g) followed by Obse variety (77.00 g) than any other partially resistant and tolerant varieties. However, for most varieties tested in this study, on the other hand, the reduction in hundred seed weight was positively correlated with the level of *Orobanche* infestation, in which hundred seed weight was highly influenced under high levels of parasite infestation. For instance, the susceptible or slightly tolerant varieties except Gachena were scored lower 100-seed weight than that of partially resistant and tolerant varieties such as Ashenge, Dedia and Obse with seed weight of 65, 68.3 and 77 g, respectively; whereas, the highly susceptible

Table 5. Combined mean of *Orobanche* emerged per plots and per plants at three host growing stages and its effects on faba bean varieties for yield and yield related traits.

Variety	Mean No. of *O.* at 3 host growth stage		OI (%)	NPE	SCM	PL	NPP	NSP	HSW g	GY kg ha^{-1}	BM kg ha^{-1}	HI (%)
	NOPP	NOPT										
Holleta-2	73.3^{fgh}	3^{cd}	76^{cd}	47.33	11.33^{fg}	5.67^{cd}	10^{ab}	3^{b}	38^{g}	386.1^{i}	3648.6^{d}	12.9^{gh}
Salale	70.4^{fgh}	2.8^{cd}	66.7^{g}	45	15^{d}	6^{bc}	8.33^{cd}	3^{b}	48.7^{ef}	869.45^{e}	2958.3^{h}	26.5^{d}
Wayu	61^{hi}	2.95^{cd}	72.8^{def}	46.67	12.67^{ef}	5.67^{cd}	9.33^{bc}	3^{b}	40^{g}	497.2^{h}	3309.7^{e}	15^{fg}
Moti	84.6^{cde}	3.9^{ab}	100^{a}	49.67	0^{h}	0.0^{f}	0.0^{e}	0.0^{d}	0^{h}	0.00k	1822.2k	0^{j}
Gebalcho	75.2^{ef}	3.2^{bcd}	100^{a}	48	0^{h}	0.0^{f}	0.0^{e}	0.0^{d}	0^{h}	0.00k	2348.6^{j}k	0^{j}
Obse	67.7^{fgh}	3.2^{bcd}	57.2^{h}	43.67	18.67^{c}	8.33^{a}	7.67^{d}	3.8^{a}	77^{b}	1418.06^{c}	3804^{c}	37^{b}
Welki	78.2^{def}	2.8^{cd}	81.9^{b}	49.67	9^{h}	4^{e}	7.33^{d}	2^{c}	49.7^{ef}	312.5^{j}	3026.4^{gh}	10.3^{hi}
Dosha	92.7^{bcd}	2.7^{cd}	100^{a}	49.67	0^{i}	0.0^{f}	0.0^{f}	0.0^{d}	0^{h}	0.00k	451.33^{fgh}	0^{j}
Mesay	43^{ij}	2.4^{d}	73.7^{de}	47	12.33^{ef}	4.67^{de}	8.33^{cd}	3^{b}	46^{f}	559.7^{g}	3068^{fg}	18.3^{e}
Tumsa	95.7^{bc}	4.3^{a}	100^{a}	50	0^{i}	0.0^{f}	0.0^{e}	0.0^{d}	0^{h}	0.00k	2945.2^{h}	0^{j}
Hachalu	77^{ef}	3.2^{bcd}	100^{a}	46	0^{i}	0.0^{f}	0.0^{e}	0.0^{d}	0^{h}	0.00k	1481.9kl	0^{j}
Bulga-70	79.6^{def}	2.64^{cd}	74.6^{de}	46	11.67^{fg}	4^{e}	8^{cd}	2^{c}	50^{e}	387.5^{i}	2651.4^{hi}	14.6^{fg}
Degaga	70.6^{fgh}	3^{b}	68.4^{fg}	46.33	14.67^{d}	6^{bc}	10^{ab}	3^{b}	59.67^{d}	1154.17^{d}	3558.3^{d}	32.4^{c}
Dedia	79.8^{def}	2.9^{cd}	54.2^{h}	46	21^{b}	6.33^{bc}	11.33^{a}	3^{b}	68.3^{c}	1709.72^{b}	4261^{b}	40^{b}
Tesfa	118.1^{a}	4.2^{a}	100^{a}	47.67	0^{i}	0.0^{f}	0.0^{e}	0.0^{d}	0^{h}	0.00k	1120.8 l	0^{j}
Gachana	104.2^{ab}	3.3^{bcd}	70.8^{efg}	48	14de	8.67^{a}	7.33^{d}	4^{a}	83.67^{a}	698.6^{f}	4212.5^{bc}	16.6^{ef}
Ashange	33^{j}	1.5^{e}	38.5^{i}	45	27.67^{a}	7.33^{ab}	11.67^{a}	4^{a}	65^{c}	3129.17^{a}	7136^{a}	43.9^{a}
Mosise	85.4^{cde}	2.6^{d}	79.2^{bc}	48	10^{gh}	5.33^{cd}	7^{d}	3^{b}	60^{d}	479.17^{h}	1880.6k	19^{e}
Aloshe	98^{bc}	3.5^{abc}	100^{a}	47	0^{i}	0.0^{f}	0.0^{e}	0.0^{d}	0^{h}	0.00k	2570.8^{hij}	0^{j}
Shalo	65.9^{gh}	2.7^{cd}	82.8^{b}	50.33	8.67^{h}	4.67^{de}	7.67^{d}	2^{c}	60.67^{d}	312.5^{j}	2959.7^{h}	9.7^{i}
CV	13.41	16.43	1.9	3.93	6.52	11.79	8.88	3.99	3.35	4.36	9.68	6.84

NOPP = Number of Orobanche per plot, NOPT = Number of Orobanche per plant, OI = Orobanche incidence, NPE = number of plant established, SCM = Stand count at maturity, PL = pod length, NPP = number pod per plant, NSP = number of seeds per pod, HSW = 100-seeds weight, GY kg ha^{-1} = grain yield per hectar, BM kg ha^{-1}= biomass per hectar, HI = harvest index. Means with the same letter per column are not significantly different.

varieties did not produce any seed and scored zero values (Table 5).

Grain yield

There were highly significant ($P \leq 0.01$) variations (Table 4) in grain yield among faba bean varieties. As the result indicated, out of twenty faba bean varieties conducted under *Orobanche* infestation, about thirteen varieties (Table 5) performed with obtaining yield in different degree of response to parasite. The maximum grain yield was obtained from Ashenge (resistance control), Dedia and Obse varieties with the values of 3129.17, 1709.7 and 1418.06 kg ha^{-1}, respectively, followed by Degaga (1154.17 kg ha^{-1}) and Selale (869.45 kg ha^{-1}) varieties. The other seven varieties did not produce yield and any other yield related traits (complete yield loss) due to their high susceptibility to the parasite, which also delayed at pod setting stage.

Biomass yield

The result obtained from analysis of variance for above ground dry matter of tested faba bean varieties indicated that there were highly significant ($P \leq 0.01$) differences between faba bean varieties (Table 4), in which the broomrapes infestation had serous effect on biomass yield. The effect of parasite on faba bean varieties was not only for grain yield, but also had great influence on crop production by reducing growth and development. Accordingly, the higher number of *Orobanche* within variety causes lower number of branches per faba bean varieties and vice-versa. However, in this study, some varieties were performed as well with good biomass performance, which might be due to their best mechanical defense.

The highest mean dry biomass weight (7136 kg ha^{-1}) was recorded from Ashenge variety (resistance control), followed by Dedia (4261 kg ha^{-1}), Gachena (4212.5 kg ha^{-1}), Obse (3804 g ha^{-1}) and Degaga (3558.3 kg ha^{-1}) varieties. On the other hand, the lowest mean dry biomass was recorded from Dosha, Tesfa, Hachalu, Moti and Gebalcho varieties with dry biomass of 451.3, 1120.8, 1481.9, 1822.1 and 2348.6 kg ha^{-1}, respectively (Table 5).

Harvest index

The performance of grain yield over biomass of twenty faba bean varieties grown under broomrapes infestation was evaluated by analyzing the percentage of theirharvest index. Analysis of variance shows that there were highly significant ($P \leq 0.01$) variations (Table 4) among tested varieties in harvest index. The maximum harvest index value was recorded from Ashenge (43.85%), Dedia (40%), Obse (37%), and Degaga (32.44%), followed by Selale variety (26.52 %). Whereas, in other varieties, the harvest index value was less than 20%, including highly susceptible varieties which were scored with 0% value of HI (Table 5). The result of this study indicated that higher grain yield producing varieties were higher in harvest index, while varieties which have a lower yield have a lower harvest index.

Level of *Orobanche* infestation at different host-growing stages

Infestation of *Orobanche* spp. on faba bean varieties at field study was determined by using different parameters on five randomly selected faba bean plants, from each plots, at three host-growing stages (at flowering stage, pod setting stage and maturity stage); the infestation of broomrapes was recorded as per plot and per plant at each growth stage (Table 6).

At host-flowering stage

(a) Number of *Orobanche* shoot emerged per plot: A significant ($P < 0.05$) variation was observed on total number of Broomrapes emerged $plot^{-1}$ in faba bean varieties at host flowering stage. The maximum number of *Orobanche* that emerged per plot was observed in highly susceptible varieties than tolerance and resistance varieties. As a result, the higher number of *Orobanche* that emerged per plot was recorded from Moti (30.33), Gebelcho and Tesfa (29) varieties, followed by Hachalu and Tumsa with values of 26.67 and 26, respectively, whereas statistically minimum number of broomrapes emerged per plot was recorded at variety Obse (6) and Dedia (8); also, there was no emerged *Orobanche* in resistance control (Ashenge) variety at host-flowering stage. However, in the remaining varieties, the number of broomrapes emerged per plot ranged from 11 to 24 (Table 6).

(b) Number of Orobanche emerged per plant: The effect of broomrapes infestation on faba bean varieties at host-flowering stage was comparatively lower due to minimum number of emerged *Orobanche* with faba bean varieties at this growing stage. However, there was significant variation ($P \leq 0.05$) among faba bean varieties in number of *Orobanche* emerged per plant. Higher number of *Orobanche* was recorded from Tesfa (2.1), Tumsa (2), Moti (1.9), and Gebalcho (1.9) varieties, whereas in other varieties there were either very few or no *Orobanche* emerged per plant at this growing stage (Table 6).

At host-pod setting stage

(a) Number of Orobanche per plot: The maximum infestation of broomrapes to faba bean varieties was observed at host-pod setting stages (Figures 1 and 2). There were highly significant ($P \leq 0.01$) difference (Table 4) in number of broomrapes emerged per plot among faba bean varieties at this stage. The higher number of Orobanche that emerged per plot was recorded from Tesfa, Aloshe, Tumsa, Gachena and Dosha varieties with 320.33, 262.67, 241, 236 and 223 respectively, followed by variety Mosise (205.67) and Moti (204). Whereas significantly minimum number (15) of emerged parasite $plot^{-1}$ was recorded from .resistance control (Ashenge) variety (Figure 3). Further, in the remaining varieties the number of broomrapes emerged per plot ranged from 100 to 186 (Table 6).

(b) Number of *Orobanche* per plant: Number of broomrapes emerged per plant highly increased, except in partially resistant variety, at host-pod setting stage comparatively than both at flowering and pod maturity stages. There was highly significant difference ($P \leq 0.01$) (Table 6) between tested faba bean varieties in number of *Orobanche* emerged per single plant. The maximum number of *Orobanche* $plant^{-1}$ was recorded from Tesfa (10.67), Moti (9), Aloshe (8), Hachalu (7) and Gachena (7) varieties, followed by Gebalcho (6.73), Holleta-2

Table 6. Mean of broomrape infestation on faba bean varieties at different host-growing stages.

Variety	At host-flowering stage		At host-pod setting		At Host-maturing stage	
	NOPP	NOPPT	NOPP	NOPPT	NOPP	NOPPT
Holeta-2	19.33^{cde}	1.07^{c}	168.33^{gh}	6.67^{cd}	32.67^{de}	1.33^{def}
Salale	15.33^{e}	0.93^{c}	139.67^{i}	5.73^{cd}	56.33^{c}	1.53^{cde}
Wayu	19.33^{cde}	1.07^{c}	136^{i}	6.3^{cd}	27.67^{def}	1.47^{cde}
Moti	30.33^{a}	1.93^{a}	204^{def}	9^{ab}	19.33^{efg}	0.87^{fg}
Gebalcho	29^{a}	1.93^{a}	177.33^{fgh}	6.73^{cd}	19.33^{efg}	0.93^{efg}
Obse	6^{g}	0.73^{c}	100.33^{j}	4.67^{d}	96.67^{a}	4.27^{a}
Welki	20^{cde}	1.07^{c}	184^{efg}	6.27^{cd}	30.67^{def}	1^{def}
Dosha	22.67^{bcd}	0.87^{c}	223^{cde}	6.4^{cd}	32.33^{de}	0.8^{fg}
Mesay	18.33^{cde}	1.2^{bc}	102.33^{j}	4.67^{d}	10.33^{gh}	1.47^{cde}
Tumsa	26^{ab}	2^{a}	241^{bc}	10^{a}	20^{efg}	0.93^{efg}
Hachalu	26.67^{ab}	1.8^{ab}	186^{efg}	7^{bc}	18.67^{fg}	0.73^{fg}
Bulga-70	21^{cd}	1.27^{bc}	183.6^{efg}	4.67^{d}	34^{d}	2^{c}
Degaga	11.33^{f}	1.07^{c}	173^{fgh}	6.4^{cd}	27.33^{def}	1.2^{def}
Dedia	7.67^{g}	0.67^{c}	150^{hi}	5.67^{cd}	81.67^{b}	3.2^{b}
Tesfa	29^{a}	2.07^{a}	320.33^{a}	10.67^{a}	5^{h}	0.47^{g}
Gachana	13.67^{ef}	1.00^{c}	236^{bcd}	7^{bc}	63^{c}	1.8^{cd}
Ashange	0.0^{h}	0.00^{d}	15k	1.53^{e}	84^{ab}	3^{b}
Mosise	17de	0.93^{c}	205.67^{cde}	5.33^{d}	33.67^{d}	1.53^{cde}
Aloshe	24.33^{bc}	1.93^{a}	262.67^{b}	8^{abc}	7^{gh}	0.53^{g}
Shalo	19.67^{cde}	1.07^{c}	150^{hi}	6^{cd}	28^{def}	1^{def}
CV (%)	9.17	15.8	9.85	12.75	11.98	13.48

NOPP = Number of *Orobanche* per plot, NOPPT = Number of *Orobanche* per plant, CV = Coefficient of variation. Means with the same letter per column are not significantly different.

Figure 1. Level of Orobanche infestation in highly susceptible varieties.

Figure 2. Level of Orobanche infestation in partially tolerant varieties.

(6.67, Dosha and Degaga (6.4), Wayu and Welki (6.3) and Shallo (6) varieties, while the lower number of

Figure 3. Level of Orobanche infestation in partially resistance variety (Ashenge).

Orobanche per plant (1.53) was recorded from Ashenge (resistance control) variety (Table 6).

At host-maturing stage

(a) Number of Orobanche per plot: There were significant ($P \leq 0.01$) differences among faba bean varieties in number of Broomrapes emerged per total plot area at host maturing stage; that is, the maximum number of *Orobanche* emerged plot^{-1} was recorded from Obse (96.67), Ashenge/resistance control (84) and Dedia (81.67) varieties, whereas the lower number of *Orobanche* that emerged per plot was recorded from highly susceptible varieties, Tesfa (4), Aloshe (5), Mesay (10), Gebelcho 19 and Hachalu (20) at this stage.

(b) Number of *Orobanche* per plant: The number of emerged broomrapes within single plant of faba bean varieties was inversely increased in partially resistant and tolerant varieties at host-maturity stage (Figure 6). There were significant differences ($P \leq 0.01$) observed among faba bean varieties for the number of *Orobanche* shoots per plant at maturity stage (Table 4 and Figures 4 to 6). The higher number of *Orobanche* shoots per plant was recorded from varieties Obse, Dedia, Ashenge, with value of 4.27, 3.2, and 3 respectively, followed by Bulga-70 (2), Gachena (1.8), Salale, Wayu, Mesay and Mosissie (1.5) varieties. Whereas the number of broomrapes emerged per plant decreased ranging from 0.47-1.3 in highly susceptible and/or susceptible varieties (Table 6), this was due to the host plants delay at the growing stage.

Figure 4. Level of Orobanche infestation in highly susceptible varieties during host physiological maturity.

Figure 5. Level of Orobanche infestation in partially tolerant varieties during host physiological maturity.

Figure 6. Level of Orobanche infestation in partially resistant variety (Ashenge) during host physiological maturity.

Effect of broomrapes on faba bean varieties and host-plant responses

Based on average results of *Orobanche* infestation during the three host growing stage, there were significant variation among faba bean varieties in their response to *Orobanche* spp. for most studied parameters. Combined mean of broomrape infestation at three host growth stage was analyzed for the total number of emerged broomrapes per plant and per plot to evaluate the performance of faba bean varieties grown with broomrapes infestation. Accordingly, the effect of *Orobanche* infestation on tested traits was statistically different between faba bean varieties at each growing stage. Highly significant differences ($P \leq 0.01$) were observed among varieties for the number of *Orobanche* shoots per faba bean plant at pod setting stage, and most of the tested traits of faba bean varieties were highly influenced by parasites, due to the fact that number of *Orobanche* that emerged per plot and per plant was highest at host pod setting stage when compared with at host-flowering and pod maturity stages.

At host-flowering stage, the number of emerged *Orobanche* spp. within varieties was much lower and had less effect on host plant. But, at pod maturity stage there were two phenomenon about number of parasite emerged within faba bean varieties: the first being that the number of broomrapes per plot and per plant become reduced in highly susceptible and slightly tolerant varieties, due to the number of plant per plot becoming delayed and the parasite also delayed with host plants; and the second, contrastingly one in which the number of emerged *Orobanche* per plant and per plot was increased in partial resistance and tolerance varieties at this host growing stage, with the host-plant not affected by parasite infection because of the pods already physiologically matured.

Accordingly, the maximum number of broomrape that emerged per plot at pod setting stage was in susceptible varieties, like Tesfa (320.33), Aloshe (262), Tumsa (241), Gachena (236), Dosha (223), Moti and Mosissie (205.67) varieties, whereas statistically lower number (15.0) of broomrapes was recorded from resistance control (Ashenge) variety. In general, nevertheless and without considering the resistance control variety, the number of broomrapes that emerged and its infection to varieties was positively associated with the reduction in performance for most traits of studied faba bean varieties. When the number of *Orobanche* that emerged per plot and per plant increases, the performance of faba bean varieties was highly influenced. However ‘Dedia and Obse’ varieties showed tolerance even though the number of emerged broomrapes was high within the varieties as compared with other varieties.

Although the infestation levels of the parasite vary from variety to variety, most of the varieties showed parasitism at field infested by broomrapes. The response of faba bean varieties to *Orobanche* infection was also varied. Accordingly, *Orobanche* incidence was significantly lower in varieties selected for their partial resistance than that of the susceptible varieties. Meanwhile, the incidence was estimated to be 100% in susceptible varieties, which indicates total yield loss. The overall broomrapes incidence ranged from 35.08-100% for tested faba bean varieties at Korem experimental site where the experiment was conducted. The evaluation of grain productivity per host-plants under *Orobanche* infested soil gives more details about the effect of parasitism on hosts. For instance, Ashenge, Dedia, Obse and Degaga varieties performed with yield of 3129, 1709.17, 1418.06 and 1154.17 kg ha^{-1}, respectively, whereas Shallo, Welki, Holleta-2, Bulga-70, Mosise, Wayu, Mesay, Gachena and Selale varieties performed with yield that ranged from 312-869 kg ha^{-1}; meanwhile that of the highly susceptible varieties were completely lost yield (zero). This shows that there were significant variations in impact levels of broomrapes infestation on faba bean grain production as well as variation in degree of host resistance/ susceptibility.

Principal component analysis (PCA)

Principal component analysis is appropriate on a number of observed variables and used as predictor or criterion

Table 7. Principal component analysis for the measured traits in faba bean varieties, and their groups based on their resistance/susceptibility levels.

Variable/trait	Group of principal component analysis		
	PC 1	PC 2	PC 3
Number of plant established (NPE)	-0.19	0.13	0.48
Number of plant harvested with yield($NPHY_W$)	0.30	0.00	0.00
Days to 50% flowering (DF)	0.14	-0.58	0.28
Days to 90% maturity (DM)	0.18	-0.27	-0.50
Plant height (PH)	0.24	0.25	-0.15
Number of nods per plant (NNP)	0.23	0.09	0.13
Pod length (PL)	0.28	0.12	0.18
Number pods per plant (NPP)	0.28	-0.01	0.28
Number of seeds per pod (NSP)	0.29	0.07	0.19
Hundred seeds weight (HSW)	0.27	0.14	0.20
Grain yield per hectar (GY kg ha^{-1})	0.28	-0.01	-0.23
Biomass yield per hectar (BM kg ha^{-1})	0.26	0.04	0.11
Harvest index (HI)	0.29	0.04	-0.15
Number *Orobanche* per plot (NOPP)	-0.19	0.51	-0.15
Number of *Orobanche* per plant (NOPT)	-0.22	0.46	-0.02
Orobanche incidence (OI)	-0.30	0.00	0.03
Eigenvalue	10.75	1.32	1.10
Difference	9.42	0.23	0.32
Explained variance (%)	67	8	7
Cumulative variance (%)	67	75	82

variables in subsequent analysis. It is typically used to analyze groups of correlated variables representing one or more common domains and to find optimal ways of combining variables into small number of subsets. PCA is mainly used as a tool in exploratory data analysis and for making predictive models. It is the simplest of the true eigenvector-based multivariate analyses. Accordingly, the mean values of sixteen quantitative traits tested for twenty faba bean varieties were computed for principal component analysis and then grouped into three principal components. The Eigen values of the three principal components for the performance of varieties which pulled out from the mean values of tested traits were 10.75, 1.32 and 1.1 with the variances of 67, 8 and 7% (Table 7), accounting for about 82% of the total variances or cumulative variation observed in faba bean performance from tested quantitative traits.

In first principal component, greater percentage of variation (about 67%) accounted due to plant height, number of nods per plant, number of pod per plant, pod length, number of seed per pod, grain yield/ha, biomass yield/ha and harvest index. The major contributors for the observed variation in the second principal component were days to flowering, plant height and number of *Orobanche* attached to plant, whereas the variation observed in the third principal component was mainly attributed to number of plant established, days to maturity, pods per plant and *Orobanche* incidence. All the values under each principal component were in the absolute values due to the fact that they represent the Eigenvector of PCA. In general, about 82% of variation was observed in the three principal components, in which greater percentage of variation accounted in the first principal component, that was largely explained by yield and yield related traits when compared to phenological traits (Table 7).

Cluster analysis

Cluster analysis was carried out for faba bean tested under field infested by *Orobanche*; thereafter, the varieties were grouped into four clusters of different sizes (Table 8 and Figure 7), with different members within a cluster assumed to be more closely related in terms of the traits under consideration with each other. Cluster 1 and 2 were the largest with 7 varieties whereas clusters 3 and 4 had 5 and 1 varieties, respectively. However, the varieties closed under the same cluster had been divided into sub partitions, with some varieties found to have good performance than the other within the same group. For example, the varieties Bulga-70 and Mosise had good degree of tolerance than the other varieties in the same group of cluster 2, and varieties Dedia and Obse were best performed than the other varieties within a cluster C-3 (Figure 1). The result obtained from cluster

Table 8. Grouping of 20 faba bean varieties in to different clusters based on their degree of resistance or susceptibility to *Orobanche* infestation under infested field study.

Cluster	Degree	No. of varieties in cluster	Designations
C1	Highly susceptible	7	Moti, Gebelcho, Dosha, Tumsa, Hachalu, Tesfa and Aloshe
C2	Susceptible	7	Welki, Shalo, Holetta-2, Bulga-70, Mosissie, Wayu and Mesay
C3	Intermediate tolerance	5	Selale, Degaga, Gachena, Obse and Dedia
C4	Partial resistance	1	Ashenge (check)

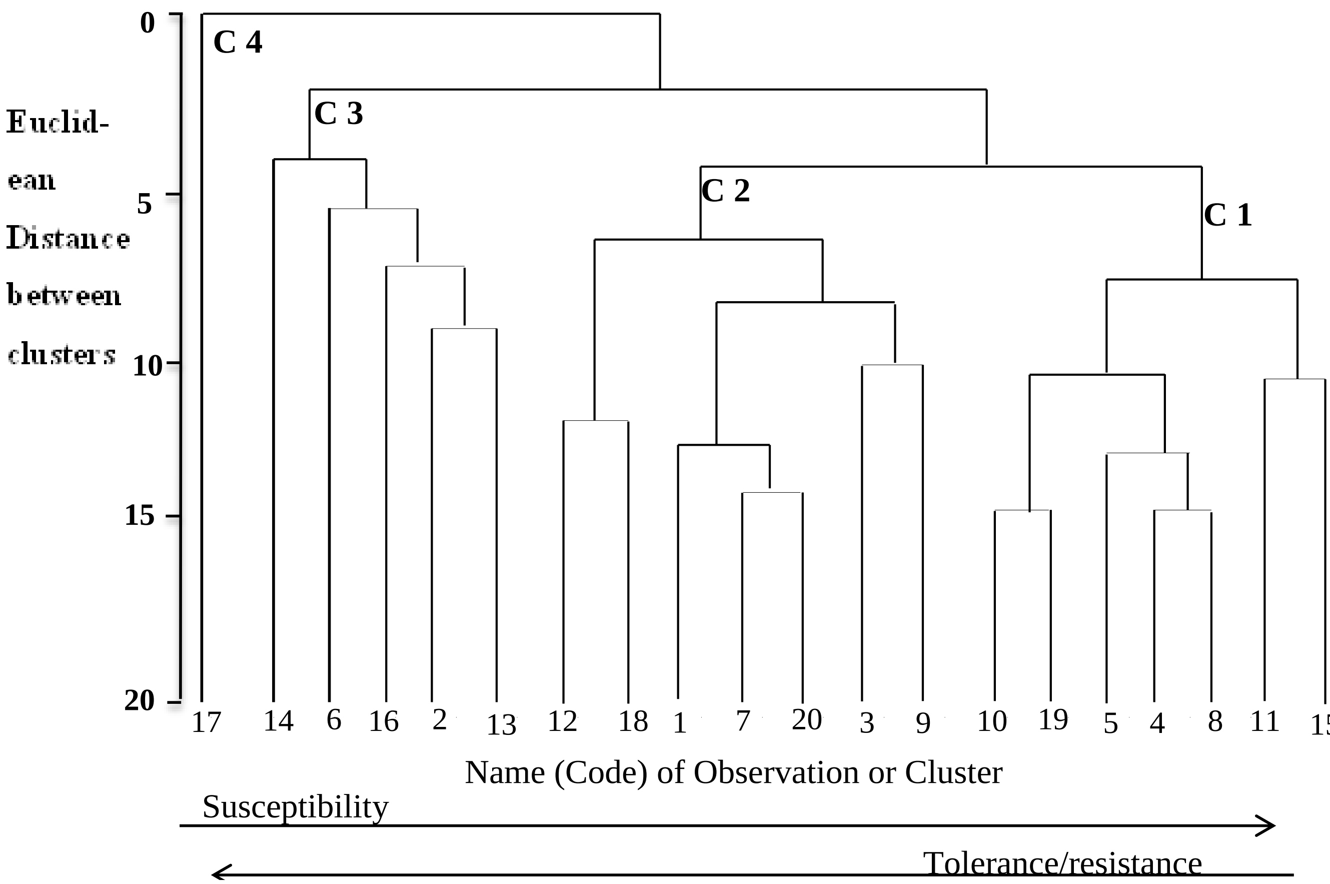

Figure 7. Dendrogram of 20 faba bean varieties evaluated for Orobanche spp. at field experiment based on average linkage cluster analysis between groups.

analysis and described as Dendrogram (Figure 1) indicated that the susceptibility levels increased from left to right, whereas the tolerance or resistance levels increased from right to left as described by the direction of the arrows.

Extent and pattern of faba bean performance under field infested by *Orobanche* infestation

The effect of *Orobanche* infestation on faba bean varieties was evaluated starting from host flowering up to pod maturity stage at field infested *Orobanche* spp. At flowering stage, the result showed that there was no significant influence of parasite on the host plants, because no more *Orobanche* weed emerged within plants. However, days to host-maturity were greatly affected by the parasite, that is, varieties with high level of *Orobanche* infection were faster to complete their life cycle than varieties within lower *Orobanche* infestation. Accordingly, the mean for days to maturity for tested varieties ranged from 114 days (susceptible) to 122 days (tolerance). Faba bean growth and developments are highly influenced by the parasite infestation. In line with this study, Rubiales et al. (2005) also reported that faba bean growth, height, and expansion of roots and branch were seriously affected under *Orobanche* infestation study.

However, in partially resistant and tolerant varieties, all phenological traits, yield and yield related traits were less affected by the parasite infection which might be due to their best host-resistance mechanisms and ability to tolerate the damage of parasites. Accordingly, the maximum plant height, nod per plant, pod per nod, pod length, seed per pod and grain yield was recorded from partially resistant or tolerant varieties Ashenge, Dedia, Obse, Degaga and Gachena in different units.

In susceptible varieties such as Welki, Shallo, Holleta-2, Bulga-70, Mosise, Wayu and Mesay, there was reduction in plant height, less ability to produce pod on their nods, reduction in number of pod per plant with few seeds per pod and minimum amount of yield recorded due to high level of *Orobanche* infection to them. However, according to Ashenafi and Mekuria (2015), those varieties were highly productive under area of non-*Orobanche* infestation.

In highly susceptible varieties such as Moti, Gebelcho, Dosha, Tumsa, Hachalu, Tesfa and Aloshe, there was extreme number of *Orobanche* that emerged per plot and per plant, which causes complete yield losses. The early parasite attachments also appear in highly susceptible varieties which might be due to the high production of stimulant by host-plants that initiate the *Orobanche* seed germination and attachments. However, at non-infested field (like Arsi and Bale), the yield produced by these susceptible varieties was great different from that of the infested field. For example, Hachalu (3436 - 4012 kg ha^{-1}), Tumsa (3497 - 3878 kg ha^{-1}), Moti (3621- 3703 kg/ha), Gebelcho (3703 - 4362 kg ha^{-1}), and Welki (4074 - 4104 kg ha^{-1}), were considered highly productive varieties (Ashenafi and Mekuria, 2015), and the faba bean varieties Dosha (3891 kg ha^{-1}), Tumsa (3437 kg ha^{-1}) and Hachalu (3271 kg ha^{-1}) at south Tigray were evaluated under *Orobanche* free site (Teama et al., 2017); whereas, in infested soil/field, the percentage reduction in grain yield of these varieties were estimated at 95- 100%.

In this study, based on their degree of resistance/ susceptibility, twenty tested faba bean varieties at infested field were grouped into four clusters: the first included the highly susceptible varieties (Moti, Gebalcho, Dosha, Tumsa, Hachalu, Tesfa and Aloshe) which were the most affected by *Orobanche* spp. with the *Orobanche* incidence close to 100%; the second group included the susceptible (Holetta-2, Wayu, Welki, Mesay, Bulga-70, Mosise and Shallo) varieties, with *Orobanche* incidence (71-90%); the third group were the varieties with intermediate tolerance to parasites (‘Dedia’, Obse, Selale, and Gachena) with incidence (60-70%); and the last group included tolerance/resistance Ashenge (resistance control) with lower parasitize or *Orobanche* incidence (<50%). Even though varieties tested under *Orobanche* infestation showed different performance in most cases, a few varieties fell under the same cluster. For instance, the third cluster “Dedia and Obse” varieties had best performed than any other varieties, next to Ashenge variety, but were however grouped with Selale, Degaga and Gachena varieties in the same cluster. This was probably due to those varieties that have related genetic background as against *Orobanche* infestation effect along with related morphological characteristics.

CONCLUSIONS AND RECOMMENDATION

Faba bean is the main source of human food in developing countries including Ethiopia and as animal feed in industrialized countries. In addition to food, many farmers in Ethiopia used the faba bean as cash crop for income purpose. However, there are different newly emerged biotic (diseases, insect pests and parasite weeds) and abiotic (drought, salinity, fertility etc.) constraints that limit the production and productivity of the faba bean.

Orobanche species are one of the serious parasitic weeds causing considerable losses in many major legumes crops especially faba bean. It is difficult to control, due to its high fecundity and long-term viability of its seed in the soil. Although other *Orobanche* species can infect leguminous plants, they are generally of little economic importance. *O. crenata*, however, has a wide host range among legumes crop, especially in Ethiopia. This parasite is known by its stout, unbranched stem, with smaller flowers. Therefore, this study was conducted under area considered highly infested by *O. crenata* located in South Tigray of Ethiopia, Korem district, to evaluate the performance of faba bean varieties under infestation.

The effect level of broomrape on faba bean varieties was determined using different parameters on five randomly selected faba bean plants, from each plot at three host-growing stages (flowering stage, pod setting stage and maturity stage). The number of emerged *Orobanche* within varieties and the infection level increased during the host-pod setting stage, but become decreased at host maturity stage especially in susceptible varieties; however, contrary to susceptible varieties, in partially tolerant or resistant varieties the number of emerged *Orobanche* increased after the host plants become physiologically matured. The extent and pattern of faba bean performance was also determined by cluster analysis for tested varieties. As a result, faba bean varieties were grouped into four clusters with different number of varieties in each cluster. Varieties with complete (100%) yield loss were grouped in cluster-1 (as highly susceptible); varieties with little amount of yield were grouped in cluster 2 (as susceptible); varieties from which medium yield was obtained were grouped in cluster 3 (as intermediate/partial tolerance); and varieties with higher yield were grouped in cluster-4 (as partial resistance).

Although the levels of effect of broomrape to faba bean plants and the degree of host-resistance was tested, there was no clear determination about ‘why the poor number of broomrapes emerged with resistance and tolerance varieties’ in this study. Therefore, more studies are needed to determine what happens when faba bean is challenged with *Orobanche* infestation, especially about: (i) deposition of obstructing compounds in the root xylem vessels of the host and mechanisms of resistance, and (ii) ways of water and nutrient flow towards the attached parasites, structure of host cell walls and lignification of the endodermal cells. In a previous study, resistance breeding attempts to achieve complete resistance to broomrape in legumes (that is, immune plants), but they did not succeed due to the complexity nature of its traits and possibly multi-genic nature of this trait. It is important to investigate repeatedly for resistance faba bean cultivars by assessing incomplete and quantitative resistance. In addition, the selection process in the faba bean program for resistance to *Orobanche* infestation on field evaluations is preferred, where natural populations of parasite occur, even though it is difficult to achieve the homogeneity of parasite seed distributions in the soil, and that of the environmental conditions can also affect the host–parasite interaction, hampering the reliable evaluations of host resistance.

Consequently, breeding for resistance is the most economic, feasible and environmental friendly method of control. In this investigation, the number of *Orobanche* seed that emerged per plot and its attachments to host plant, especially at host pod setting stage were the appropriate screening methods and effective selection indices. However, this study was conducted only on single location and under *Orobanche*-infested field. Therefore, future studies and research works are needed to investigate further the parasite-host reaction across a location or conducting the experiment both under infested and non-infested areas. Besides, the next breeding program should be mainly targeted on the improvement of faba bean plants by re-evaluation of partially resistant and tolerant varieties gained by this finding. Also, crossing of Ashenge variety with Dedia variety or Ashenge with Obse variety can lead to a positive response, including molecular analysis using QTLs and MAS, biochemical studies for solving these serious problems, as well as provide high yielding faba bean material that are tolerant or resistance to *Orobanche* spp.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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