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Performance of faba bean genotypes with *Orobanche foetida* Poir. and *Orobanche crenata* Forsk. infestation in Tunisia

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Orobanche foetida Poir. and *O. crenata* Forsk. are major constraints to faba bean (*Vicia faba* L.) cultivation in Tunisia. To evaluate the different levels of resistance of seven small-seeded faba bean genotypes to these parasitic weed species, three trials were conducted in fields infested and non-infested with *O. foetida* in the Oued Beja Agricultural Experimental Unit and *O. crenata* in an experimental field at Ariana of the National Institute of Agricultural Research during three cropping seasons. Compared to the susceptible cv. Badï, the seven genotypes showed moderate to high levels of resistance to both *Orobanche* species. The number and dry weight of emerged broomrapes and underground tubercles recorded on the new improved genotypes were lower than those recorded on released and resistant 'Najeh' and 'Baraca'. The parasitism index on the new genotypes varied from 2-6 times less than susceptible 'Badï' in both Oued-Beja and Ariana. Yield reduction due to *O. foetida* infection varied from 13.5% on genotype XAR-VF00.13-89-2-1-1-1-1 to 59.7% on 'Baraca', whereas the yield loss was about 92% on the susceptible control. Parasitic infection did not affect dry grain protein accumulation in the tested genotypes.

Key words: Broomrape, *Vicia faba*, resistance, Tunisia.

INTRODUCTION

Orobanche species (broomrapes) are chlorophyll-lacking root parasites of many cultivated crops such as legumes, sunflower, and tobacco (Joel et al., 2007; Parker, 2012). The total infested areas in Tunisia vary from 5 000 to 10 000 ha (Kharrat and Souissi, 2004) for legumes. In many infested fields, farmers avoid growing faba bean (*Vicia faba* L.) and other susceptible crops, resulting in substantial reductions of both grain production and cultivated areas (Kharrat and Souissi, 2004). Infestation by broomrape has been also reported on *Lathyrus odoratus* L., grass pea (*L. sativus* L.), *Trifolium alexandrinum* L., *Medicago truncatula* Gaertn., and *V. sativa* L. subsp. *amphicarpa* (L.) Batt. in Tunisia (Kharrat, 2002a). *Orobanche crenata* Forsk. has parasitized a wide host range since antiquity, e.g. faba bean, pea (*Pisum sativum* L.), lentil (*Lens culinaris* Medik.), vetch (*V. sativa*), grass pea, and forage legumes (Rubiales et al., 2006); it causes great damage to faba bean crops and notable yield losses. In Tunisia, faba bean is infested by two *Orobanche* species, *O. foetida* Poir. and *O. crenata*. The latter is mainly distributed in eastern Tunisia while the former is restricted to the western and north central areas especially the Beja region (Kharrat and Halila, 1994). Fetid broomrape (*O. foetida*) constitutes a serious threat mainly to faba bean cultivation and causes yield losses of 66%-83% (Abbes et al., 2008). Only peas among grain legumes escape *O. foetida* attacks (Kharrat, 1999).

Various cultural and chemical strategies have been used to control *O. foetida* (Kharrat and Halila, 1994; Abbes et al., 2010a) and *O. crenata* (El-Shirbini and Mamdouh, 2004; Pérez-de-Luque et al., 2004b) on faba bean. Unfortunately, most of them alone are not effective or have insufficient success due to the longevity in soil, small size, and high fecundity of *Orobanche* seed (Díaz-Ruiz et al., 2009). An integrated control strategy based on the use of resistant varieties remains the most likely economical and feasible control method (Pérez de-Luque et al., 2010; Maalouf et al., 2011). In Tunisia, research activities on *Orobanche* parasitic weeds has intensified since the 1990s, mainly on faba bean in order to select new high-yielding faba bean varieties locally adapted to the Tunisian environment and resistant to both *O. foetida* and *O. crenata*. The national faba bean program released the first partially resistant faba bean cultivar ('Najeh') in 2009 (Kharrat et al., 2010) and registered it in the Tunisian Official Catalogue of Plant Variety.

This study aimed to examine the degree of resistance of seven faba bean genotypes selected for their

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resistance to *O. foetida* and *O. crenata* and to determine the effects of broomrape infestation on crop productivity and quality in reference to partially resistant cultivars Najeh and Baraca and susceptible ('Badï') in diverse environments.

MATERIALS AND METHODS

Ten faba bean genotypes were evaluated against both *Orobanche* spp., seven advanced lines and three released varieties: 'Badï' as the susceptible control and 'Najeh' and 'Baraca' as partially resistant controls (Table 1).

The trials for evaluating genotypes for resistance to *O. foetida* were conducted during three consecutive cropping seasons (2009-2012) in both heavily *Orobanche*-infested and non-infested soils at Oued Beja Agricultural Experimental Unit (36°44' N; 9°13' E; 150 m a.s.l.) in north-west Tunisia in a sub-humid climate with moderate winters (average annual rainfall of 600 mm). The monthly rainfall and average temperature distribution for the three cropping seasons are presented in Figure 1. The genotypes were evaluated in a randomized complete block design with three replicates. Each plot consisted of four rows of 4 m length and 0.5 m inter-row spacing (8 m^2). During the three cropping seasons, sowing was during the first week of December with a seeding rate of 24 seeds m^{-2}.

The 10 genotypes were also evaluated for resistance to *O. crenata* in an infested field in the National Institute of Agricultural Research (INRAT) experimental field at Ariana (36°50' N, 10°11' E; 7 m a.s.l.) The trial was a randomized complete block design with three replicates, and each genotype was sown during the first week of December in a single row of 4 m length and an inter-row spacing of 0.3 m (1.2 m^2).

Table 1. Pedigree, origin, and main characteristics of studied faba bean genotypes.

Genotype/Pedigree	Origin/characteristics
G1: XAR-VF00.12-12-3-1-3-1	Cross performed in Tunisia (Ariana) in 2000
G2: XAR-VF00.13-8-3-1-1-1-1	Cross performed in Tunisia (Ariana) in 2000
G3: XAR-VF00.13-89-2-1-1-1-1	Cross performed in Tunisia (Ariana) in 2000
G4: XBJ92.10-27-1-1-1-1-1	Cross performed in Tunisia (Oued Beja) in 1992
G5: XBJ92-10-46-1-3-1-2-1-1-1-6-A	Cross performed in Tunisia (Oued Beja) in 1992
G6: XBJ90.04-6-2-1-1-4-C	Cross performed in Tunisia (Oued Beja) in 1990
G7: XBJ90.04-2-3-1-1-1-2A	Cross performed in Tunisia (Oued Beja) in 1990
G8: 'Baraca'	Spain/Partially resistant to *Orobanche crenata*
G9: 'Najeh'	Small-seeded variety released in 2009/Partially resistant to *Orobanche foetida* and *O. crenata*
G10: 'Badï'	Small-seeded variety released in 2004/Susceptible to *O. foetida* and *O. crenata*

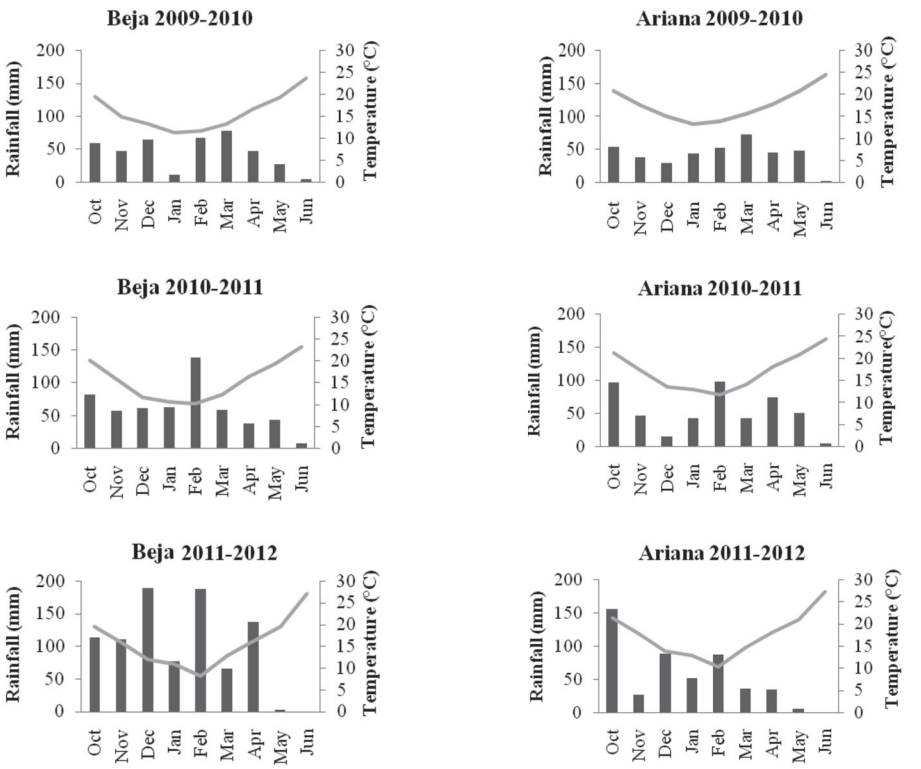

Figure 1. Monthly average temperature (°C) and precipitation (mm) during the three cropping seasons of 2009-2010, 2010-2011, and 2011-2012 in two experimental stations (Oued Beja and Ariana, Tunisia).

Data collection and analyses

Resistance/susceptibility levels of faba bean lines were determined using several parameters on three randomly selected plants, from each plot, at two growth stages (pod setting and maturity). At pod setting stage, the number of emerged and non-emerged *Orobanche* and total *Orobanche* dry weight per plant were recorded. The *Orobanche* were classified according to their development stages using a 1-5 scale (Labrousse et al., 2001): 1 = attachment of haustoria to host root, 2 = small tubercles without root development, 3 = tubercles with crown roots without shoot formation, 4 = underground tubercles with shoot formation and 5 = emergence of spikes. The dry weight was measured after drying fresh samples at 80 °C for 48 h. At maturity stage, the following parameters were recorded on the two central rows at Oued Beja and one single row at Ariana: number of *Orobanche* shoots, total *Orobanche* dry weight, *Orobanche* incidence (percentage of faba bean plants presenting emerged *Orobanche* shoots per plot), *Orobanche* severity using a 1-9 scale (Abbes et al., 2007a), parasitism index = (incidence × severity)/100, grain yield, 100 seed weight, and protein content. The N percentage (NP) was determined using 100 mg of dried milled faba bean seed infested or not by *O. foetida* using the micro-Kjeldahl method (AOAC, 1975). The protein content was calculated from NP × 6.25.

ANOVA was performed using the SPSS statistical program v.15 (IBM Corporation, Armonk, New York, USA). Mean comparisons were made using Duncan's multiple-range test at $P = 0.05$.

RESULTS AND DISCUSSION

There were highly significant differences among genotypes in response to *O. foetida* and *O. crenata* for most studied parameters. In the three cropping seasons, genotypes showed parasitism indexes in the range of 1-4.1 compared to 6.9 for susceptible 'Badï' in fields infested by *O. foetida*, and correspondingly 0.7-2.4 compared to 6.9 for *O. crenata* infestation (Table 2). *Orobanche* severity and incidence were significantly lower (both $P < 0.001$) for the selected genotypes than the susceptible control 'Badï'. Incidence was estimated to be close to 100% in both Oued Beja and Ariana infested fields for 'Badï', indicating uniform infestation of both sites. Nevertheless, and without considering the susceptible control, the incidence was 32%-84% at Oued Beja for *O. foetida* infestation and 25%-59% at Ariana for *O. crenata* infestation. Of tested lines, 'Badï' presented the highest severity (> 7) for both *Orobanche* species. The parasitism index (which integrates both parameters) gives an accurate level of resistance of the tested genotypes and enabled classifying the studied genotypes into three groups: the first included the susceptible 'Badï' which was the most affected by *O. foetida* and *O. crenata*, with the highest parasitism index (Table 2); the second group included genotypes with intermediate resistance to *O. foetida* ('Baraca', G4, and G5) and *O. crenata* (G1, G4, and 'Baraca'); and the last, with lower parasitism index were G6, G7, G3, G1, G2, and 'Najeh' for *O. foetida* and G5, G6, G7, 'Najeh', G3, and G2 for *O. crenata*, had the highest resistance.

Highly significant differences ($P < 0.001$) were observed among genotypes for the number of *Orobanche* shoots per faba bean plant at maturity stage (Table 3). The lowest numbers of *Orobanche* shoots per plant were for genotypes G6, G7, 'Najeh', G3, G5, and G2 with *O. foetida* infestation and G5, G6, G7, 'Najeh', G3, G2, and G4 with *O. crenata* infestation, whereas 'Badï' had 2.3 and 4.2 shoots per plant, respectively. The variation in infestation level among different seasons can be explained by the specific climatic conditions of each season. Based on average results of the three seasons, the total number of emerged *Orobanche* shoots per plant and *Orobanche* dry weight (Table 4) were significantly (both $P < 0.001$) lower than 'Badï' for the selected genotypes. Among the tested genotypes, G6 was slightly infested by both *Orobanche* species and showed the lowest number and dry weight of *Orobanche* for both species.

Evaluations of non-emerged (underground) attachments at faba bean pod setting stage showed further differences that were not detectable when only the number of emerged broomrapes was considered at the maturity stage. At pod setting there were significant differences ($P < 0.001$) between studied genotypes (Figure 2). Among the genotypes, G6 showed the lowest infection level by

Table 2. Estimated parasitism index recorded for faba bean genotypes during the cropping seasons 2009-2010, 2010-2011, and 2011-2012.

	Orobanche foetida-Oued Beja				*Orobanche crenata*-Ariana			
Genotypes	2009-2010	2010-2011	2011-2012	Mean	2009-2010	2010-2011	2011-2012	Mean
G1	2.2ab*	1.0a	4.1bc	2.5ab	2.7ab	3.1a	0.9ab	2.3bc
G2	3.3ab	0.3a	3.8abc	2.5ab	1.9ab	2.9a	0.1a	1.8ab
G3	1.1a	1.0a	3.3abc	1.9ab	1.9ab	2.4a	0.1a	1.6ab
G4	4.2bc	1.9ab	5.8bcd	4.1cd	3.3b	2.1a	1.4b	2.4bc
G5	3.0ab	1.8ab	4.7bcd	3.2bc	0.4a	1.4a	0.0a	0.7a
G6	1.4a	0.7a	1.0a	1.0a	0.4a	1.5a	0.0a	0.8a
G7	1.2a	0.4a	2.9ab	1.5a	0.7a	1.4a	0.0a	0.8a
'Baraca'	5.3bc	3.5b	6.3cd	5.0d	1.8ab	4.7b	1.7b	3.0c
'Najeh'	2.8ab	1.5a	3.3abc	2.6ab	1.5ab	2.1a	0.0a	1.3ab
'Badï'	6.8c	6.3c	7.6d	6.9e	6.5c	8.5c	5.2c	6.9d

Data with the same letter per column are not significantly different according to Duncan's test ($P = 0.05$).

Table 3. Number of emerged *Orobanche* at crop maturity for faba bean genotypes during cropping seasons 2009-2010, 2010-2011, and 2011-2012.

	Orobanche foetida-Oued Beja				*Orobanche crenata*-Ariana			
Genotypes	2009-2010	2010-2011	2011-2012	Mean	2009-2010	2010-2011	2011-2012	Mean
G1	2.1a*	0.4bc	2.4c	1.6cde	1.6a	2.8abc	0.4a	1.7b
G2	2.3a	0.0a	1.6abc	1.3abcd	1.8a	1.8ab	0.0a	1.2ab
G3	1.3a	0.2ab	1.4abc	0.9abc	1.4a	1.3ab	0.0a	0.9ab
G4	1.8a	0.5c	2.0bc	1.4bcd	1.7a	1.5abc	0.4a	1.5ab
G5	1.4a	0.3abc	2.0bc	1.2abcd	0.1a	0.7a	0.0a	0.3a
G6	1.4a	0.2abc	0.3a	0.7a	0.2a	0.8a	0.0a	0.5a
G7	0.9a	0.3ab	1.1abc	0.8ab	0.4a	1.0a	0.0a	0.5a
'Baraca'	2.6a	1.1d	1.5abc	1.8ab	0.9a	3.6bc	0.5a	2.0b
'Najeh'	1.2a	0.2abc	0.9ab	0.8ab	0.7a	1.5ab	0.0a	0.9ab
'Badï'	2.8a	2.1e	1.8bc	2.3e	4.5b	4.5c	3.7b	4.2c

Data with the same letter per column are not significantly different according to Duncan's test ($P = 0.05$).

Table 4. Total dry weights (g) of emerged *Orobanche* per plant at crop maturity for faba bean genotypes during cropping seasons 2009-2010, 2010-2011, and 2011-2012.

	Orobanche foetida-Oued Beja				*Orobanche crenata*-Ariana			
Genotypes	2009-2010	2010-2011	2011-2012	Mean	2009-2010	2010-2011	2011-2012	Mean
G1	4.8ab*	1.9c	5.3c	4.0cde	2.3bc	3.2ab	0.4a	2.1ab
G2	8.1b	0.2a	3.7bc	4.0cde	2.3bc	2.6ab	0.1a	1.7ab
G3	4.8ab	0.7ab	3.8bc	2.9bcd	1.4ab	1.8ab	0.0a	1.1ab
G4	3.2ab	1.7c	4.3c	3.1bcd	1.9abc	3.0ab	0.4a	2.5ab
G5	3.2ab	1.3bc	3.7bc	2.7abcd	0.2a	0.5a	0.0a	0.3a
G6	1.9a	0.6ab	0.8a	1.1a	0.2a	0.7a	0.0a	0.3a
G7	1.6a	0.6ab	2.7abc	1.6ab	0.5a	3.2ab	0.0a	1.3ab
'Baraca'	6.2ab	3.6d	3.6bc	4.5de	1.2ab	6.1b	0.4a	3.2bc
'Najeh'	4.2ab	1.4bc	1.5ab	2.4abc	0.7ab	2.2ab	0.0a	1.1ab
'Badï'	6.8b	5.7e	4.5c	5.7e	3.4c	4.5ab	7.9b	5.2c

Data with the same letter per column are not significantly different according to Duncan's test ($P = 0.05$).

O. foetida and *O. crenata* with averages of 1.3 and 1.0 tubercles per plant, respectively (Figure 2). G5 (0.83 g) and G6 (1.1 g) showed the lowest *Orobanche* attachment dry weights for *O. crenata*, and G2 and G7 infected with *O. foetida* had 2.3 and 2.6 g, respectively (Table 5). More than 70% of the parasite attachment reached stage 5 for 'Badï' infested by *O. foetida*, compared with an average of 39% for the seven tested genotypes; the lowest percent attachment (stage 5) was for the G7 genotype (13.3%). In the Ariana field infested by *O. crenata* the lowest tubercle stage 5 percentage was for G5 (24%).

Under high *Orobanche* infections, the susceptible 'Badï' was the most affected in all cropping seasons compared to other genotypes (Tables 6 and 7). Grain yield of all the new improved genotypes was higher than the partially resistant 'Najeh' at both locations. Genotype G3 (9.9 g plant^{-1}) gave the highest grain yield under *O. foetida* infestation (Tables 6 and 7) during the three cropping seasons. Under *O. crenata* infestation genotype G5 had the highest seed yield (7.1 g plant^{-1}). Nevertheless, G6 presented similar seed production in both Oued Beja and Ariana (7.2 and 7.03 g plant^{-1}, respectively). The highest

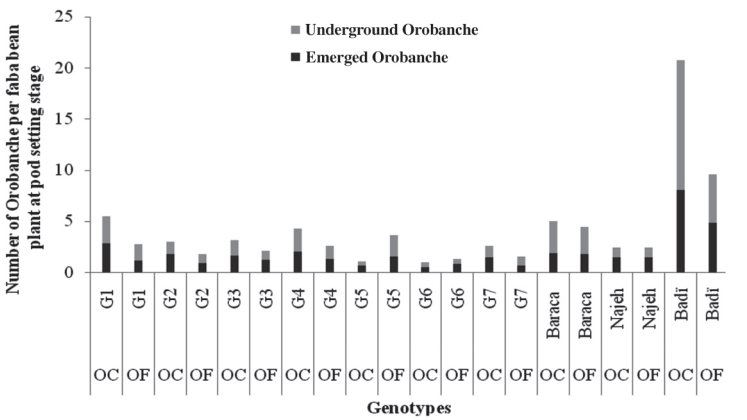

Figure 2. Number of *Orobanche* (emerged spikes and underground attachments) per faba bean plant in Ariana (OC) and in Oued Beja (OF), Tunisia, at pod setting stage (average of three cropping seasons).

Table 5. Total *Orobanche* dry weight (g) per faba bean plant at the beginning of crop maturity for faba bean genotypes during cropping seasons 2009-2010, 2010-2011, and 2011-2012.

	Orobanche foetida-Oued Beja				*Orobanche crenata*-Ariana			
Genotypes	2009-2010	2010-2011	2011-2012	Mean	2009-2010	2010-2011	2011-2012	Mean
G1	0.9a*	0.8ab	13.0cd	4.1ab	0.9b	6.2bc	0.8a	4.2d
G2	0.6a	1.4ab	7.4a	2.6a	0.6b	3.6ab	0.0a	2.9cd
G3	1.6a	2.2abc	6.1a	3.0a	2.4a	6.4bc	0.1a	3.3cd
G4	1.0a	5.8cd	10.6abc	4.8ab	4.4b	7.0c	0.3a	4.3d
G5	0.6a	2.6abc	12.8bcd	4.4ab	1.3a	0.9a	0.0a	0.8a
G6	0.1a	1.0ab	10.7abc	3.2a	0.9a	2.0a	0.1a	1.1ab
G7	0.0	0.0	8.8abc	2.3a	2.2a	3.7ab	0.3a	2.3bc
'Baraca'	3.7b	4.8bc	12.2bcd	6.2b	2.5a	8.0c	0.3a	3.9d
'Najeh'	0.5a	2.6abc	8.3ab	3.1a	2.3a	5.8bc	0.2a	3.0cd
'Badï'	14.0c	8.9d	15.6d	13.1c	10.1c	12.2d	6.0b	9.8e

Data with the same letter per column are not significantly different according to Duncan's test ($P = 0.05$).

Table 6. Grain yield (g plant^{-1}) for faba bean genotypes during cropping seasons 2009-2010, 2010-2011, and 2011-2012.

	Orobanche foetida-Oued Beja				*Orobanche crenata*-Ariana			
Genotypes	2009-2010	2010-2011	2011-2012	Mean	2009-2010	2010-2011	2011-2012	Mean
G1	8.9cd*	12.6b	6.3c	9.3cd	6.1b	4.3ab	9.5e	6.3bc
G2	4.2abc	13.0b	5.8c	7.6bcd	4.9b	6.4bc	5.0b	5.8bc
G3	11.2d	13.1b	5.6c	9.9d	3.3ab	7.0bc	8.4de	6.2bc
G4	5.0abc	10.5b	4.0bc	6.5bc	7.1b	4.3bc	6.5bcd	6.1bc
G5	3.3ab	11.0b	4.6bc	6.3b	6.7b	8.9c	5.0b	7.1bc
G6	5.9bc	10.0b	5.6c	7.2bc	6.6b	7.2bc	7.3cd	7.0c
G7	7.2bcd	8.3b	3.9bc	6.6bc	4.0ab	6.2bc	6.2bc	5.7bc
'Baraca'	3.0ab	8.5b	3.9bc	5.1b	5.4b	6.0bc	10.0e	7.0bc
'Najeh'	4.1abc	11.1b	1.5ab	5.7b	2.6ab	5.3bc	5.4bc	4.6b
'Badï'	0.3a	1.4a	0.4a	0.7a	0.1a	0.0a	1.4a	0.5a

Data with the same letter per column are not significantly different according to Duncan's test ($P = 0.05$).

Table 7. One-hundred seed weight (g) for faba bean genotypes during cropping seasons 2009-2010, 2010-2011, and 2011-2012.

	Orobanche foetida-Oued Beja				*Orobanche crenata*-Ariana			
Genotypes	2009-2010	2010-2011	2011-2012	Mean	2009-2010	2010-2011	2011-2012	Mean
G1	61.6c*	65.2c	55.1c	60.6c	80.0d	86.2c	72.1c	80.1f
G2	42.6ab	46.0a	44.7ab	44.4a	51.4b	50.8b	53.5b	51.8bc
G3	49.7abc	60.3bc	54.1c	55.3bc	61.6bcd	56.6b	64.4c	60.4cd
G4	55.8bc	59.9bc	47.4abc	54.3bc	78.0d	63.7b	81.0d	73.1ef
G5	40.9ab	48.6a	41.6a	43.7ab	55.4bc	53.0b	42.0a	50.4bc
G6	40.5ab	41.8a	40.2a	40.8a	51.7b	49.3b	50.9ab	50.5bc
G7	42.0ab	47.2a	45.0ab	44.7ab	49.0b	45.3b	48.5ab	47.4a
'Baraca'	57.1bc	56.4b	50.9bc	54.8bc	73.9cd	62.6b	66.5c	67.2de
'Najeh'	49.2abc	56.3b	53.4c	52.9bc	46.9b	58.9b	49.3ab	52.4bc
'Badï'	31.5a	45.1a	44.4ab	40.4a	24.1a	10.5a	46.4ab	25.3a

Data with the same letter per column are not significantly different according to Duncan's test ($P = 0.05$).

seed weight was recorded for G1 for both *Orobanche* spp., and the lowest on 'Badï' also for both species. Percent yield reduction from *O. foetida* infestation reached 92.6% for 'Badï' and the lowest were for G3, G6, and G7 (13.5%, 28.2%, and 34.9%).

There were no significant differences in protein content among genotypes due to *Orobanche* infestations. Proteins levels in grains were close to 23% dry weight and did not vary significantly with presence of *Orobanche* (Figure 3).

The behavior of the selected faba bean genotypes was investigated in soil infested by and free of *O. foetida* at Oued Beja, and a field infested with *O. crenata* at Ariana, during three cropping seasons 2009-2010, 2010-2011, and 2011-2012. Several parameters have been used by different authors to evaluate the levels of resistance in infested fields: height of parasitic flowering spikes, weight and number of emerged spikes of *Orobanche* per host plant, and rate of reproduction (Rubiales et al., 2003b; 2006). Knowing that *Orobanche* attack is related to growth vigor of the host and competition for resources among attachments (Aalders and Pieters, 1987), indices based only on size and weight of broomrapes can be misleading (Fernández-Aparicio et al., 2007). Thus, Sillero et al. (1996) indicated that the health of the host plant must be considered in *Orobanche* evaluations, and screening and selection based only on *Orobanche* emerged number can also be misleading.

In the present study, in addition to the number and weight of emerged shoots of *Orobanche* per host plant, severity, incidence, and parasitism index were also used to

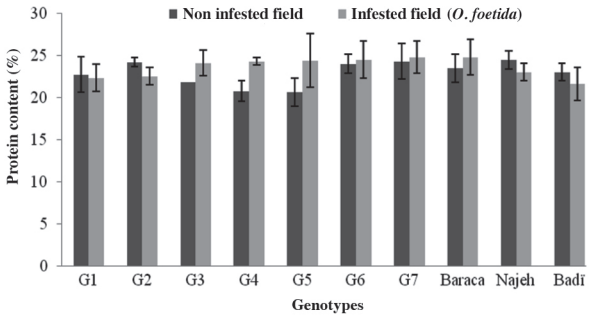

Figure 3. Grain protein content for faba bean genotypes during the cropping season 2009-2010 in fields infested and non-infested with *Orobanche foetida*.

measure levels of resistance and growth vigor of the host. The degree of attack by the parasite was higher in 'Badï' than other genotypes. The Spanish 'Baraca', developed from the parent 'Giza 402' (Nadal et al., 2004), was still less resistant to *O. foetida* than *O. crenata* compared to resistant 'Najeh' and the seven other lines.

Most of the new genotypes showed few broomrape attachments, especially genotypes G6 and G7 for *O. foetida* and G5 and G6 for *O. crenata*. Nevertheless, the total number and dry weight of underground and emerged parasites at the two growth stages of the crop were correlated with the resistance level previously established and based on incidence, severity, and parasitism index.

Contrary to the reactions of 'Giza 402' and 'Baraca' infected with *O. crenata* (Nadal et al., 2004), no necrosis of attached tubercles was observed on the new genotypes for both *Orobanche* species. Similar results were observed by Abbes et al. (2007a; 2007b; 2010b) and no necrosis was reported, confirming that only some mechanisms of resistance of the parent 'Giza 402' against *O. crenata* were observed in our resistant genotypes. The difference in the behavior observed for 'Baraca' infested by *O. crenata* can be attributed to the *O. crenata* population (Román et al., 2002; Abbes et al., 2010b).

Many successes have been reported in breeding for broomrape resistance in faba bean (Fernández-Aparicio et al., 2012; 2014) and several accessions have been developed. In Tunisia, resistance to *O. foetida* has been identified in much faba bean germplasm. 'Najeh', recently registered in 2009 in the Tunisian Varietal Catalogue by INRAT (Kharrat et al., 2010), is characterized by a low number of underground and emerged *Orobanche* with no parasite necrosis (Abbes et al., 2007a; Kharrat et al., 2010). Its resistance is also related to a deeper root system of the host (Abbes et al., 2007b), to a low soluble invertase activity in *O. foetida*, to a low osmotic potential of the infected roots, and to the organic N deficiency of the host phloem sap (Abbes et al., 2009a; 2009b). Nevertheless, as reported by Rubiales et al. (2006), only moderate to low levels of incomplete resistance of complex inheritance against parasitic weeds has been identified in other crops, such as in legumes against *O. crenata*, *O. foetida*, and *O. aegyptiaca* (Kharrat, 2002b; Rubiales et al., 2009; Fernández-Aparicio et al., 2014).

The evaluation of grain productivity per host plant in *Orobanche* free and infested soil gives more details about the effect of parasitism on hosts. The impact of *O. foetida* infestation on faba bean grain production varied with genotype. Generally, parasitism greatly decreased grain yield, but the partially resistant genotypes were less affected. In non-infested field, 'Badï' was considered a productive cultivar, whereas in infested soils the percentage reduction in grain yield reached 91.7%. In contrast, the productivity of 'Najeh' and other genotypes selected for resistance to *O. foetida* in infested soil was less affected and grain yield reduction was 15.5%-60% (Table 8). Losses in seed yield, especially in the first cropping season of 2009-2010, could be related to variations in weather conditions, which are known to influence *Orobanche* infection and faba bean growth (Rubiales et al., 2003a; Abbes et al., 2010b).

Fetid broomrape did not show significant impact on seed protein accumulation. These observations should be confirmed using grain produced in other cropping seasons. Moreover, Abbes et al. (2007a) observed a decrease in the protein/starch ratio in faba bean plants infected by *O. foetida* and a negative effect of *Orobanche* attack on nutritional quality of grain. In cowpea parasitized by *Striga gesnerioides* (Willd.) Vatke or *Alectra vogelii* Benth., an increase in grain protein content was observed

Table 8. Grain yield (g plant^{-1}) and one-hundred seed weight (g) for faba bean genotypes during cropping seasons 2009-2010, 2010-2011, and 2011-2012 in a field not infested by Orobanche at Oued Beja experimental unit.

	Grain yield (g plant^{-1})				Mean reduction	One-hundred seed weight (g)			
Genotypes	2009-2010	2010-2011	2011-2012	Mean	(%)	2009-2010	2010-2011	2011-2012	Mean
G1	13.8e*	18.6e	14.8c	15.8d	40.9	68.5e	58.3d	55.7c	60.8h
G2	9.7bcd	12.1abc	13.9c	11.9bc	35.7	51.8bc	47.2bc	49.2abc	49.4cde
G3	11.7de	11.4ab	11.4abc	11.5abc	13.5	56.8cd	52.1cd	53.6bc	53.8efg
G4	11.0cde	16.2cde	18.4d	15.2d	56.8	62.3de	57.2d	55.4c	58.3gh
G5	5.2a	17.0de	11.9bc	11.3abc	44.6	47.0ab	52.2cd	46.5abc	48.6bcd
G6	8.5abcd	10.2a	11.4abc	10.0ab	28.2	46.5ab	40.8ab	44.6ab	44.0ab
G7	7.1ab	12.5abc	10.9abc	10.2ab	34.9	45.7ab	42.4ab	51.6abc	46.6bc
'Baraca'	11.8de	13.6abcd	13.0c	12.8c	59.7	59.5cd	51.7cd	55.1c	55.4fg
'Najeh'	6.4ab	15.4bcde	8.2a	10.0ab	43.1	54.0bcd	52.2cd	49.4abc	51.9def
'Badï'	7.7abc	11.7ab	7.9a	9.1a	91.6	42.0a	37.8a	41.6a	40.4a

Data with the same letter per column are not significantly different according to Duncan's test ($P = 0.05$).

and could be related to the reduced grain yield in infected plants and, in parallel, to the enhanced N contents in leaves (Alonge et al., 2001; 2005). Further studies on the effect of broomrape parasitism on protein accumulation in faba bean seeds are suggested.

CONCLUSIONS

In conclusion, the seven tested genotypes, selected for their partial resistance to *Orobanche foetida* and *O. crenata*, showed a high level of resistance under field conditions. These genotypes can be promoted as new varieties or used in breeding programs to develop new resistant lines.

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