

## Does the level of resistance to *Acanthoscelides obtectus* of bean genotypes (*Phaseolus* spp.) change according to the seed production environment?

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Received: April 19<sup>th</sup>, 2024; Accepted: July 2<sup>nd</sup>, 2024; Published: July 16<sup>th</sup>, 2024

**Abstract.** Bean weevil (*Acanthoscelides obtectus*) cause considerable losses in warehouses in dry bean (*Phaseolus vulgaris* L). *Phaseolus acutifolius* varieties could be used for genetic studies and genetic improvement of common beans. Tepary bean varieties resistance was studied produced with irrigation and under drought conditions to *A. obtectus*. Previously, we studied *A. obtectus* colony from Spain with some of these bean varieties. In the present research, we studied a different *A. obtectus* colony from México. The varieties T-amarillo, PS-AZH-15 and T-cafe beans showed a lower ovoposition. T-amarillo, T-negro and T-cafe increased the duration of the insect biological cycle. In the varieties T-cafe, T-negro and T-amarillo increased larvae mortality before burrowing the seed in percent and reduced the number of first generation adults. Little grain weight loss is caused by small number of emerged adults, in the varieties T-amarillo, PS-AZH-15, T-cafe and T-negro. According with adult's number of first generation and grain weight loss in percent T-amarillo showed resistance and tolerance to *A. obtectus* infestation and it could be used as source of resistance for *P. vulgaris* breeding. No significant differences were found according to the seed production environment for any traits studied except for initial seed weight. Resistant varieties maintain their lethality regardless of the seed production environment. Probably *A. obtectus* is genetically different according to the area and is adapted to the varieties produced in each country or region.

**Key words:** bean bruchid, common bean, *P. acutifolius*, insect resistance.

## INTRODUCTION

Dry bean (*Phaseolus vulgaris L.*) is an important staple crop in many countries, it is an excellent source of protein of low cost, and this legume has vitamins, minerals (Admassu Shimelis & Kumar Rakshit, 2005) as well as secondary metabolites with biological activity that help to prevent some types of cancer in humans (Cid-Gallegos et al., 2023). In 2018, harvested area with common bean, around the world, exceed 22.7 million of hectares with 28.4 million of tones (FAOSTAT, 2022).

Dry bean production is affected around the world by biotic and abiotic factors (Beebe & Corrales, 1991). Some of the major biotic constraints involving post-harvest losses caused by the bruchid species *Acanthoscelides obtectus* Say and *Zabrotes subfasciatus* Boheman. The common bean weevil *Acanthoscelides obtectus* (Coleoptera: Bruchidae) is a global problem that causes serious damage on warehouses in regions of Latin America, Africa and Europe (Schmale et al., 2003; Silva et al., 2007). The bean weevil is the main postharvest pest of dry bean, Some studies have reported losses from 7 to 40% caused by weevil damage (Mbogo et al., 2009). This represents worldwide losses, each year of 1.95–11.16 million of tones due to weevil damage. A research carried on in Honduras in the 90's showed that the postharvest losses could reached up to US\$3.5 million dollars (Espinal et al., 2004). Infestations are more commonly detected in storage (Parsons & Credland, 2003). Females place their eggs in groups under or close to a single seed. The beetles spend their larval and pupal phases inside seeds, where the first instars larvae burrow. The last larvae stage dig chambers directly below the seed and a tiny circular aperture can reveal the existence of a larva. Unlike the majority of other bruchids, it attacks both stored seeds and field-grown beans, it has a continuous reproductive cycle without diapause (Tucić et al., 1996; Ahmed et al., 2019). Eggs are milky white color with oval shape, the larva passes through six instars with no significant differences in length or head capsule between the instars, the pupa is white-yellow color and the adult is grayish to blackish color (Ahmed et al., 2019).

There are a number of ways to control bean weevils some examples are: the use of essential oils from the next plants: *Foeniculum vulgare*, *Artemisia dracuncululus*, *Lavandula angustifolia*; and isolates from entomopathogenic fungus (*Metarhizium anisopliae*) (Lak et al., 2022), *Bauveria bassiana* (Gutiérrez Jirón, 2016), *Trichoderma spp* (Rodríguez-González et al., 2019). The egg predatory mites *Blattisocius tarsalis* and *Amblyseius swirskii* have been tested as natural enemies to control bean weevils with an efficacy of 60%, on the other side the larvae parasitoids *Anisopteromalus calandrae* and *Lariophagus distinguendus* reduced up to 38% of the pest population (Iturralde-García et al., 2020). Great farmers with large warehouses can use chemical pesticides to control the bean weevil. At the contrary, small farmers could use resistant varieties as control strategy (Mbogo et al., 2009).

Genetic breeding for pest resistance should increase grain yield contributing to a more permanent supply of common beans in countries around the world (Mbogo et al., 2009). The common bean resistant varieties against *A. obtectus*, has a number of advantages over chemical control or others. Chemical pesticides need to be repeated periodically, therefore are more expensive in comparison with the use of resistant varieties; in addition the use of chemical insecticides is associated with insecticide resistance, eradication of beneficial insects and environmental contamination (Keneni et

al., 2011). The best approach for this pest is to develop resistant lines to *A. obtectus*, the most difficult bruchid to control. For example, the number of adults present after 182 days of seed storage was low for all Tepary accessions and was high for most common bean accessions; Tepary bean may provide a useful germplasm source for *Phaseolus vulgaris* breeding (Shade et al., 1987). Seed storage protein ‘arcelin’ has been previously described as causing antibiosis against *Z. subfasciatus*, without providing protection against *A. obtectus* (Cardona & Kornegay, 1999; Osborn et al., 1988; Minney et al., 1990). However Osborn et al. (1988) mention that the arcelin, causes sub lethal effects in *A. obtectus* larvae, increasing the biological cycle of *A. obtectus* and reducing their adult weight. Resistance is also associated with lectin-like seed storage proteins (LLPs) (Sales et al., 2000), and  $\alpha$ -amylase inhibitor (Fory et al., 1996). In particular, moderate resistance to *A. obtectus* has been found by Cardona et al. (1990), Kornegay & Cardona, (1991) and Kornegay et al., 1993). Seven allelic arcelin variants with differential value for insect resistance have been reported so far, with arcelin-1 (Acosta-Gallegos et al., 1998; Cardona et al., 1990; Hartweck et al., 1997). Arcelin not only prolongs the development of *A. obtectus* but also extends the period of adult emergence, thus contributing to a higher variation of host stages present at the same time (Schmale et al., 2003; Velten et al., 2008).

In the highly resistant accession G12952, resistance was expressed as antibiosis causing delayed and reduced adult emergence, high mortality of late first instar larvae, reduced female fecundity, and negative rates of population growth. The factors responsible for resistance are present in the cotyledons of seeds and are chemical in nature (Cardona et al., 1989). The natural storage protein arcelin, in G12952, causes sub-lethal effects to the bruchid *A. obtectus* (Schoonhoven et al., 1983; Kornegay & Cardona, 1991), prolonging immature development of young bruchid larvae, extending the period of adult emergence, and reducing adult weight (Osborn et al., 1988; Velten et al., 2007).

No other sources of bruchid resistance have been detected in over 17,000 bean genotypes originating elsewhere in Latin America (Valencia et al., 2006). Few genotypes with high resistance to *A. obtectus* were found: G40199 (*Phaseolus acutifolius* A. Gray) (Kusolwa & Myers, 2011), G02770 (*P. vulgaris*), QUESS (*P. vulgaris*) (Zaugg et al., 2013), G12952 (*P. vulgaris*) (Schoonhoven et al., 1983). Recently T-amarillo and T-negro, Tepary bean varieties, were reported as resistant accessions against *A. obtectus* (Jiménez et al., 2017). And after that was reported a dominant gene for resistance to *A. obtectus* in both crosses P-salttillo  $\times$  T-amarillo and T-amarillo  $\times$  T-cafe using number of adults as resistance criteria (Jiménez-Galindo et al., 2020).

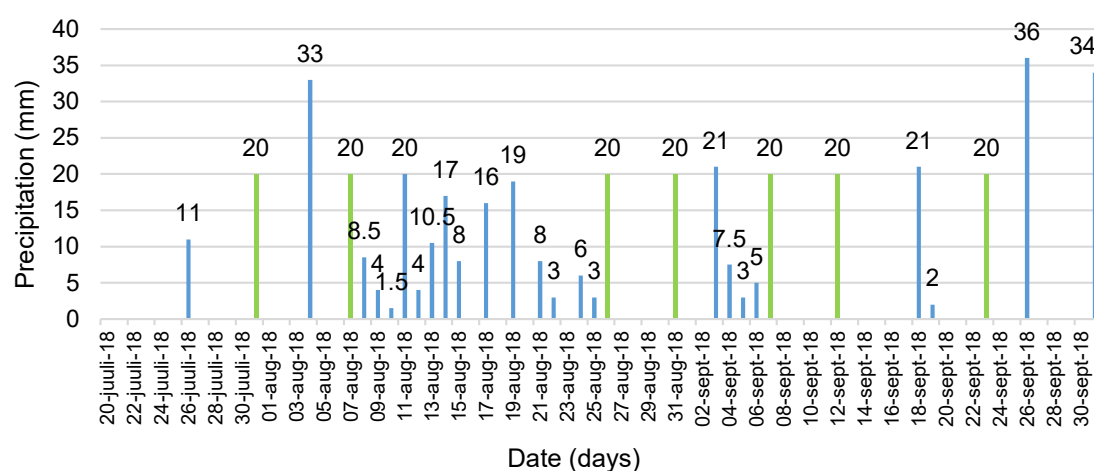
The novelty of this manuscript is to study how the resistance level of bean genotypes change according to seed production environment. And indirectly to validate that genetically *A. obtectus* from Spain is different of *A. obtectus* from Mexico.

## MATERIALS AND METHODS

### Seed material

We used ten dry bean varieties PS-AZH-15, Aluyori, PS-AZH-15/1, Azufrado Higuera (A-higuera), Rosa Bufa 60 (R-bufa-60), Pinto Saltillo (P-salttillo), Rosa Bufa-80 (R-bufa), Tepary cafe (T-cafe), Tepary amarillo (T-amarillo), and Tepary negro (T-negro). The irrigation-drought experiments were sown on July 20, 2018 and finished

on October. Performed at the Experimental Station of INIFAP in Bachiniva, Chihuahua, Mexico: 28° 47' 19.32" N, 107° 16' 11.64" E, at an altitude of 2,012 meters above sea level. In a clay loam soil with 43% sand, 28.7% silt and 28.2% clay, free of salts, high in organic matter content (2.01%). The fertilizer formula 30-50-00 was applied in both experiments. The experimental unit consisted of 1 furrow 5 meters long with 60 seeds at a distance of 8.4 cm between seeds and 0.75 m between furrows. In 2018 it rained 302 mm from July 20 to October 1, 2018 and was the total water in drought experiment. On the irrigation experiment, 20 mm irrigations were also added on July 31, August 7, August 26, August 31, September 7, September 12 and September 23 for a total of 442 mm. The application of water through irrigation are represented in green bars (Fig. 1). All seeds were harvested in 2018 from two bioassays under irrigation and drought (Table 1).



**Figure 1.** Precipitation and irrigation in field irrigation-drought trials in 2018 at Experimental Station of INIFAP in Bachiniva, Chihuahua.

**Table 1.** Characteristic of seeds of ten bean varieties from INIFAP evaluated for resistance to *A. obtectus*

Variety	Race	Species	Growth habit	Seed size
PS-AZH-15	Nueva Granada	<i>P. vulgaris</i>	II	Large
Aluyori	Nueva Granada	<i>P. vulgaris</i>	II	Large
PS-AZH-15/1	Nueva Granada	<i>P. vulgaris</i>	II	Large
A-higuera	Nueva Granada	<i>P. vulgaris</i>	II	Large
R-bufa-60	Durango	<i>P. vulgaris</i>	III	Medium
P-saltillo	Durango	<i>P. vulgaris</i>	III	Medium
R-bufa	Durango	<i>P. vulgaris</i>	III	Medium
T-cafe	Wild type	<i>P. acutifolius</i>	III	Small
T-amarillo	Wild type	<i>P. acutifolius</i>	III	Small
T-negro	Wild type	<i>P. acutifolius</i>	III	Small

### Experimental design

With the seed from the field experiments harvested in November 2018, two bioassays were performed on September 5, 2019 and finished on December 20, 2019 an average temperature of 22 °C in the Genetics laboratory from Experimental Station of INIFAP, in Cuauthemoc, Chihuahua, Mexico 28° 24' 15" N, 106° 52' 19" E, at an altitude

of 2050 meters above sea level. We used a completely randomized design with four replicates. We put 5 males and 5 females with 20 seeds per repetition, in plastic bottles of 5 cm diameter and 5.5 cm of height. The variables measured were: 1) 20 seed weight (g), 2) number of eggs (n), 3) larvae number (n) (that is equal to the number of eggs), 4) larvae mortality before entering the seed (n), 5) larvae mortality before entering the seed (%) [Calculated with formula:  $MLBES = \text{larvae mortality before to entering the seed (n)} * 100 / \text{larvae number (n)}$ ], 6) number of adults (n), 7) grain weight loss (g) [calculated with formula:  $SWL = \text{initial seed weight} - \text{final seed weight, after the first generation of adults}$ ] and 8) biological cycle (days) calculated from start of bioassays to the first adult emergence on each repetition.

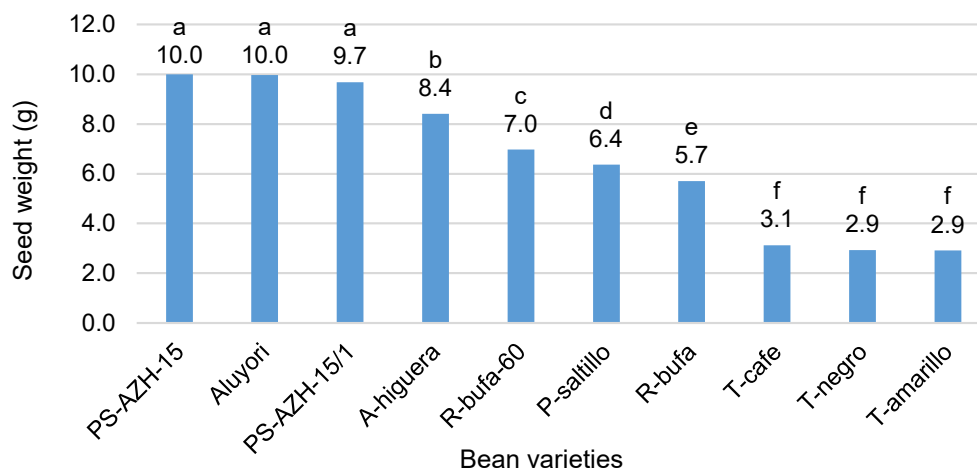
### Statistical analysis

The analysis of the databases of the two trials was used a General Linear Model (PROC-GLM) in statistical package SAS 9.3 (SAS Institute, 2016). For mean comparisons was used the test of *MSD* (Minimum Significant Difference) from *LSD* at  $p < 0.05$ .

## RESULTS AND DISCUSSION

### Seed weight

Significant differences were found according to the seed production environment for seed weight. Significant statistical differences were found between varieties for seed weight. The best varieties that show high seed weight were PS-AZH-15, Aluyori and PS-AZH-15/1. The varieties with less seed weight were T-amarillo, T-negro and T-cafe (Fig. 2).

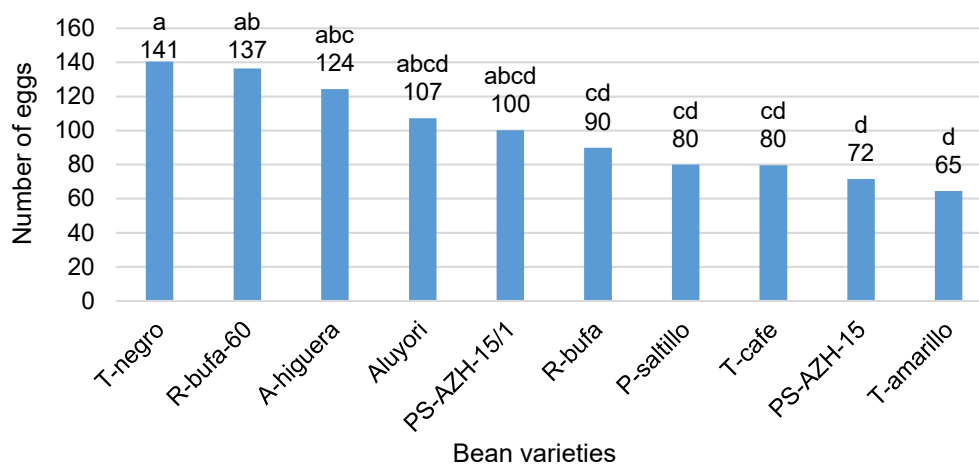


**Figure 2.** Twenty seed weight for 10 bean varieties. DMS = 0.55. Means followed by the same letter are not significantly different ( $LSD = 0.05$ ).

In the present study, significant differences were found according to the seed production environment and varieties for initial seed weight, because one seed was produced under irrigation conditions and the other under rainfed conditions. The results agree with Abdalla et al. (2015) that found that the seed size and other yield components change according with the production environment.

### Number of eggs

There are no differences between environments for number of eggs. Significant differences were found for number of eggs between varieties. The variety with more number of eggs was T-negro. The varieties with less number of eggs were T-amarillo and PS-AZH-15 (Fig. 3).



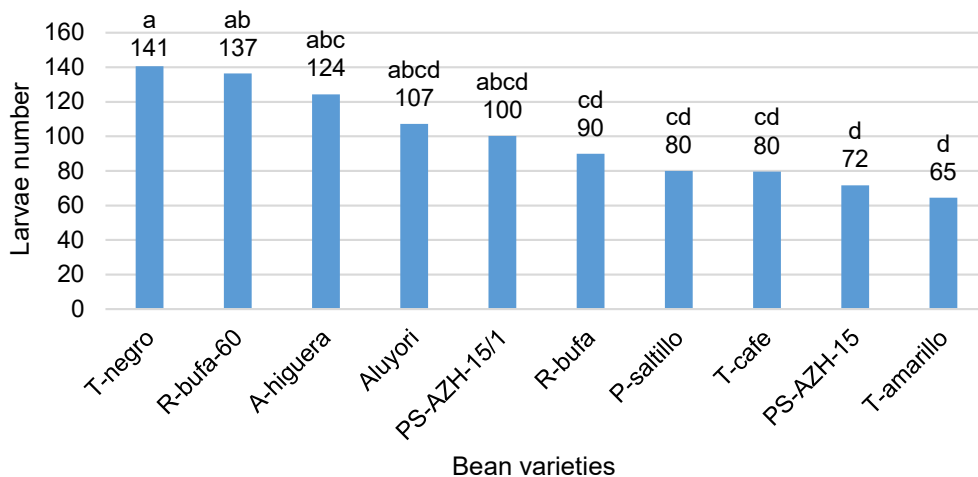
**Figure 3.** Number of eggs in 10 bean varieties. DMS = 49.3. Means followed by the same letter are not significantly different ( $LSD = 0.05$ ).

Jiménez et al. (2017) found several mechanism of resistance to *A. obtectus* including a compound in seed coat that keeps the adult inactive for a long time, avoiding also oviposition. Contrastingly with Velten et al. (2007) that found varieties with high level of arcelines in cotyledons where females lay less number of eggs. Jiménez et al. (2017) found that the varieties with more number of eggs were PS-AZH-15, T-cafe and P-saltillo and the varieties with less were T-negro and T-amarillo with *A. obtectus* recollected and reared in Pontevedra, Spain. In the present study contrastingly, the varieties with more number of eggs were T-negro, R-bufa-60 and A-higuera and less P-saltillo, T-cafe, PS-AZH-15 and T-amarillo. This means that probably *A. obtectus* could be adapted to each variety that exists in each region around the world. Interestingly T-amarillo is the most resistant variety per number of eggs for both *A. obtectus* colonies, from Spain and Mexico. However, T-negro it is the one that allows the oviposition of *A. obtectus* of Mexico in the present study and decreases to oviposition of *A. obtectus* of Spain (Jiménez et al., 2017). This supports that probably the plague is genetically different in the different regions of the world, but we need more bioassays with *A. obtectus* colonies from Spain and from Mexico. Some other authors have found genetic differences between insect populations. According to our research Sword & Chapman, (1994) found that the differences in the feeding habits in different parts of their distribution of Green Bird Grasshopper (*Schistocerca gossypii*) are not simply due to the difference in food availability of different populations, but are also probably based on genetic differences between individuals. Also Jones, (1987) reported a detailed study of cabbage white butterfly (*Pieris rapae*) feeding was carried out in two populations of

native Europe, but it reached Australia where it was observed that there is a great difference in the behavior of females from different regions. When the two populations were subjected to the same environmental and food conditions, the differences were maintained, even in successive generations. Which means that probably, as in our studies of *A. obtectus*, the pests are most likely genetically different and are adapted to different environmental and nutritional conditions. In addition Bonal et al. (2019) reported differences between acorn feeding insects (*Curculio* spp.) of California and the Spain using DNA taxonomy technique. At the intra-specific level, Californian *Curculio* showed a much more marked population genetic structure compared to Iberian ones, in which genetic depauperation and a posterior intense inter-population gene-flow can be appreciated.

### Larvae number

There are no differences between environments for larvae number variable. Significant statistical differences for number of larvae between varieties were found. The variety with more number of larvae was T-negro. The varieties with less number of larvae were T-amarillo and PS-AZH-15 (Fig. 4).



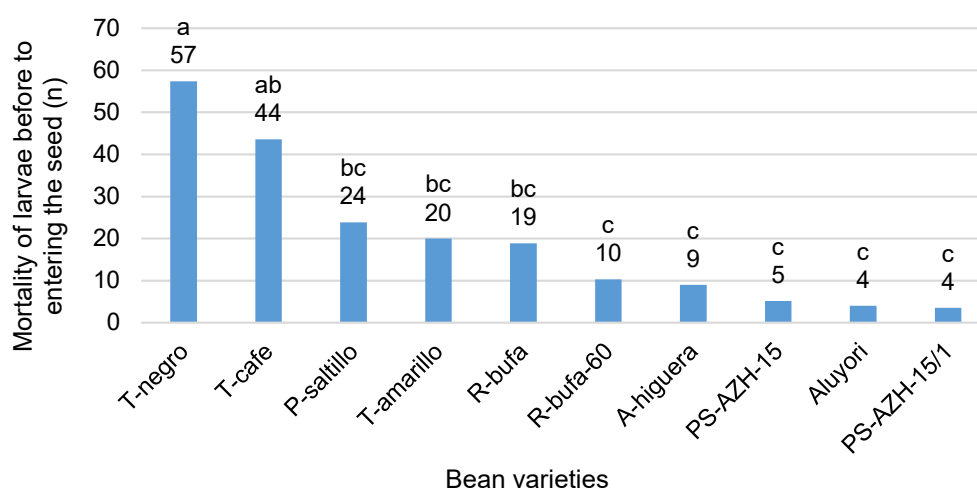
**Figure 4.** Larvae number in 10 bean varieties. MSD = 49.3. Means followed by the same letter are not significantly different ( $LSD = 0.05$ ).

### Larvae mortality before entering the seed (n)

There are no differences between environments for larvae mortality before to entering the seed (n). Significant statistical differences were found between varieties for larvae mortality before entering the seed (n). The varieties with more mortality of larvae were T-negro and T-cafe. The varieties with less mortality of larvae were PS-AZH-15/1, Aluyori and PS-AZH-15 (Fig. 5).

Jiménez et al. (2017) found a possible volatile compound located in testa, causing larval mortality. Such compound keeps adults inactive, avoiding oviposition, adult and larvae antixenosis, larval mortality and is not located in cotyledons, suggesting that they should be different from arcelines. These results are according with Valencia et al. (2006) that found low percentage of survivor of larvae in G40199. In addition,

Jiménez et al. (2020) found pipecolic acid in testa in two F<sub>2</sub> populations between T-amarillo × P-salttillo and T-cafe × T-amarillo as the responsible metabolite that keeps under control *A. obtectus* and is related to effective larvae mortality before to entering the seed and zero adults emerged from resistant lines. Jiménez et al. (2017) found that the varieties with high larvae mortality before to entering the seed were T-negro (96.1%), T-amarillo (77.6%), T-cafe (77.2%) and P-salttillo (66.2%) and less PS-AZH-15, something according with present research, where we found that the genotypes with high larvae mortality before to entering the seed were T-cafe (49.5%), T-negro (42.8%) and T-amarillo (32.5%). The mortality of larvae is lower to *A. obtectus* from Mexico and changes the order of the varieties for larvae mortality before to entering the seed, which probably means that insect pest from Spain and from Mexico, are genetically different. The varieties with less larvae mortality before entering the seed in the present study were P-salttillo, PS-AZH-15, according with Jiménez et al. (2017), PS-AZH-15/1, Aluyori, R-bufa-60, A-higuera and R-bufa. The larvae mortality before entering the seed is a very interesting resistance trait of the varieties and very few studies had quantified it, of the few reports are the authors Schmale et al. (2003) and Velten et al. (2008). Also Velten et al. (2008) found larvae mortality from 20% to 35% before entering the seed in the bean variety RAZ 94 and are according with our present results.

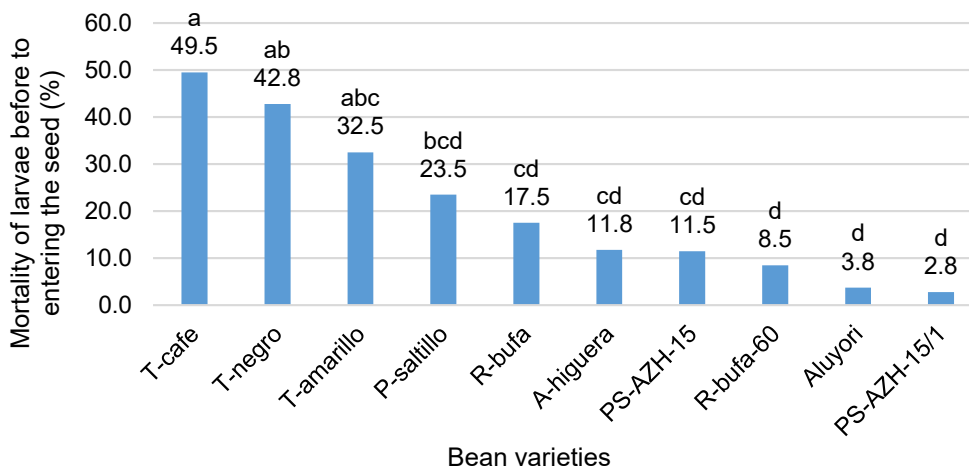


**Figure 5.** Larvae mortality of before entering the seed in number for 10 bean varieties. DMS = 28.7. Means followed by the same letter are not significantly different ( $LSD = 0.05$ ).

#### Larvae mortality of before entering the seed (%)

There are no differences between environments for larvae mortality before entering the seed (%). Significant statistical differences between varieties were found for larvae mortality before entering the seed (%). The varieties with high larvae mortality were T-cafe, T-negro and T-amarillo. The varieties with less mortality of larvae were PS-AZH-15/1, Aluyori and R-bufa-60 (Fig. 6).

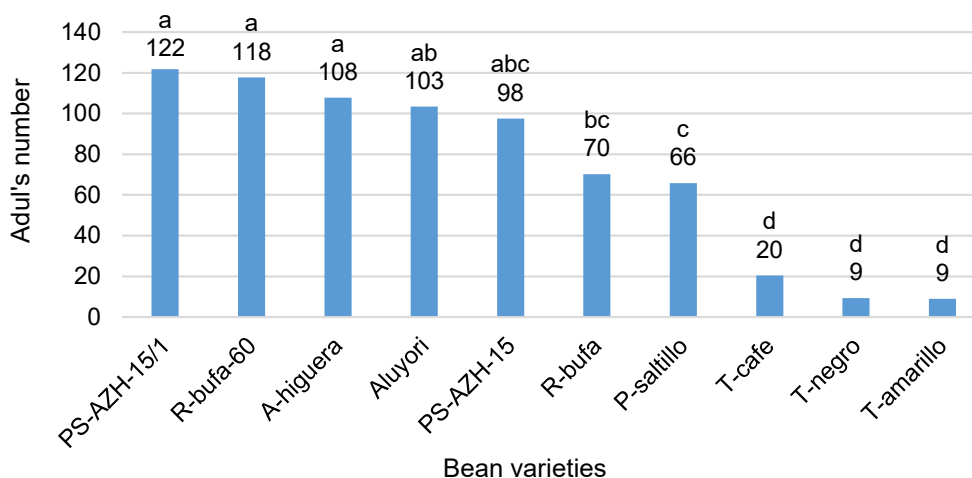




**Figure 6.** Mortality of larvae before to entering the seed in 10 bean varieties. DMS = 21.8. Means followed by the same letter are not significantly different ( $LSD = 0.05$ ).

#### Adult's number

There are no differences between environments for adult's number. Significant statistical differences between varieties were found for adult's number. The varieties with high adults number were PS-AZH-15/1, R-bufa-60, A-higuera, Aluyori and PS-AZH-15. The varieties with less adult's number were T-amarillo, T-negro and T-cafe (Fig. 7).



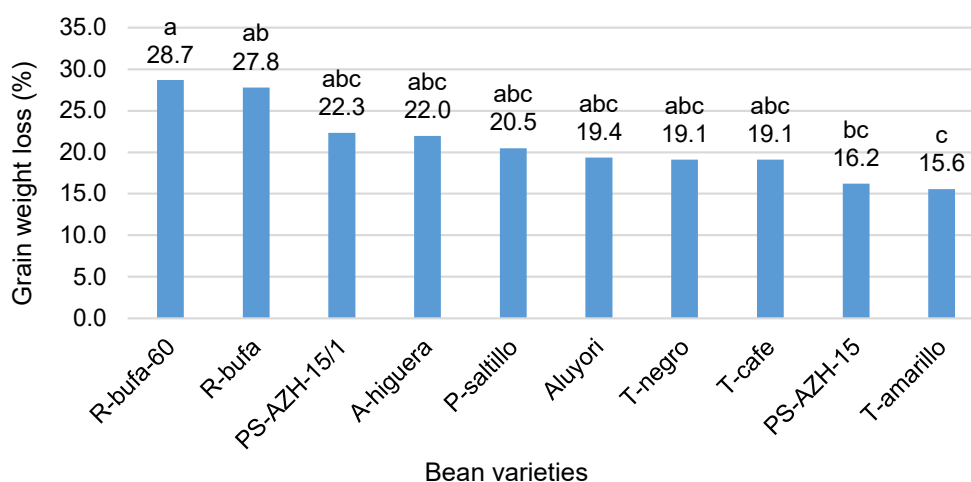
**Figure 7.** Number of adults in 10 bean varieties. DMS = 37.3. Means followed by the same letter are not significantly different ( $LSD = 0.05$ ).

The varieties with more number of emerged adults of *A. obtectus* from Spain in the first generation were PS-AZH-15 (235) and P-saltillo (113) and less T-amarillo (2), T-negro (7) and T-cafe (36) (Jiménez et al., 2017). In present study we found that the varieties with more number of adults emerged from first generation of *A. obtectus* from México were PS-AZH-15/1 (122), R-bufa-60 (118 adults), A-higuera (108 adults), Aluyori (103 adults) and PS-AZH-15 (98) and interestingly the varieties are the same

with less number of adults T-amarillo (9 adults), T-negro (9 adults) and T-cafe (20 adults). The three varieties most resistant, by number of 1<sup>st</sup> adults generation, to *A. obtectus* from Spain agree with the same three that are more resistant to *A. obtectus* from Mexico. Armenta-López et al. (2021) reported Azufrado Higuera and Aluyori as resistant genotypes; at the contrary in our study we found Azufrado Higuera and Aluyori as susceptible genotypes.

### Grain weight loss (%)

There are no differences between environments for grain weight loss (%). Significant differences were found for grain weight loss between varieties. The varieties with more grain weight loss were R-bufa-60 and R-bufa. The varieties with less grain weight loss were T-amarillo and PS-AZH-15 (Fig. 8).



**Figure 8.** Grain weight loss in percent for 10 bean varieties. DMS = 8.8. Means followed by the same letter are not significantly different ( $LSD = 0.05$ ).

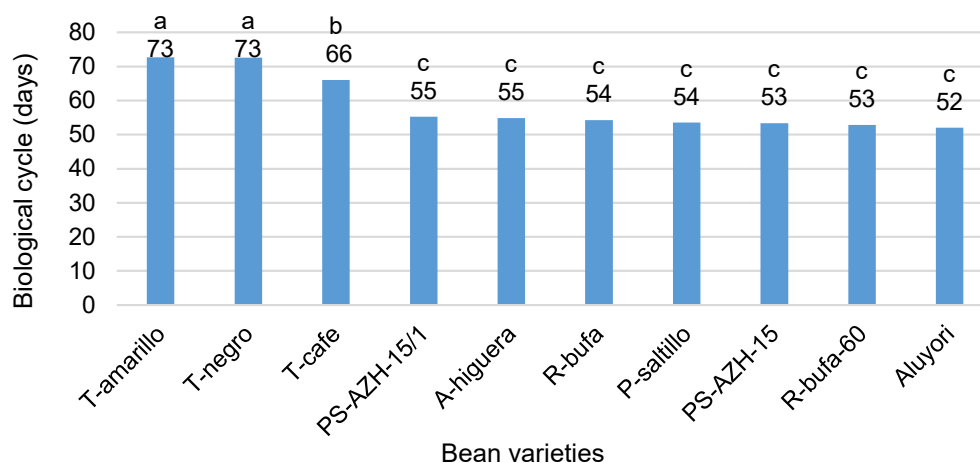
Jiménez et al. (2017) reported PS-AZH-15 and P-salttillo as susceptible varieties with more grain weight loss (%) and three resistant varieties with less grain weight loss T-amarillo, T-negro and T-cafe. The results of previous research are different to present study because we found that the most susceptible varieties were R-bufa-60 and R-bufa. Likewise, P-salttillo, T-negro and T-cafe show the same level of susceptibility to *A. obtectus* from Mexico. The consistent variety is T-amarillo for resistance to both bruchids from Spain and Mexico.

### Biological cycle (days)

There are no differences between environments for biological cycle. Significant statistical differences were found between varieties for biological cycle. The varieties that showed the longest biological cycle were T-amarillo, T-negro and T-cafe. The varieties with the shortest biological cycle were the rest (Fig. 9).

Velten et al. (2007) found that the arcelines in cotyledons provide clear evidence of growth inhibitor on first instar larvae. Jiménez et al. (2017) reported the biological cycle in winter and the duration of the biological cycle for the varieties at 10.5 °C was

106.5 days for T-amarillo, 98 for T-negro, 65.3 for T-cafe, 54.5 for P-salttillo and 50.8 for PS-AZH-15. These results are according with present research because we found a cycle for T-amarillo and T-negro of 73 days, 66 for T-cafe, 55 for PS-AZH-15/1, 54 for P-salttillo and 53 days for PS-AZH-15. The two bioassays were carried out at medium temperature of 14 °C. These results are consistent with Schmale et al. (2003) who reported that adult emergence in resistant varieties was from 45 to 95 days (RAZ 36, RAZ 94 and RAZ 104), while in susceptible varieties it ranges from 20 to 48 days, in the Calima bean variety.



**Figure 9.** Biological cycle in days for 10 bean varieties. DMS = 5.2. Means followed by the same letter are not significantly different ( $LSD = 0.05$ ).

## CONCLUSIONS

The resistance level of the varieties do not changes according to the seed production environment. The most resistant varieties to *A. obtectus* from Mexico are T-amarillo, T-negro and T-cafe being T-amarillo the most resistant variety for *A. obtectus* from Mexico. The most resistant varieties had smaller seed size, lower number of eggs and larvae (except T-negro, higher larval mortality, lower number of first generation adults, lower grain weight loss and longer biological cycle. T-negro has the highest number of eggs and larvae, however, also the highest number of dead larvae before entering the seed in number and percentage. The consistent variety is T-amarillo for resistance to both bruchids from Spain and Mexico. Probably *A. obtectus* from Spain is genetically different of *A. obtectus* of Mexico. The most susceptible varieties were PS-AZH-15/1, R-Bufa-60, A-higuera and Aluyori. Susceptible varieties had greater seed size, greater number of eggs and larvae, lower larval mortality, greater number of first generation adults, greater grain weight loss (except PS-AZH-15), and greater biological cycle. PS-AZH-15 presented one of the largest seed sizes; however, within the varieties with the highest seed weight, it presented a lower number of eggs and larvae and therefore lower number of adults emerged from the first generation and lower grain weight loss or lower consumption.

## REFERENCES

- Abdalla, A.A., Ahmed, M.F., Taha, M.B. & El Naim, A.M. 2015. Effects of Different environments on yield components of Faba Bean (*Vicia faba* L.). *International Journal of Agriculture and Forestry* **5**(1), 1–9. doi: 10.5923/j.ijaf.20150501.01
- Acosta-Gallegos, J.A., Quintero, C., Vargas, J., Toro, O., Tohme, J. & Cardona, C. 1998. A new variant of arcelin in wild common bean, *Phaseolus vulgaris* L., from southern Mexico. *Genetic Resources and Crop Evolution* **45**, 235–242. doi: 10.1023/A:1008636132108
- Admassu-Shimelis, E., Kumar-Rakshit, S. 2005. Antinutritional factors and in vitro protein digestibility of improved haricot bean (*Phaseolus vulgaris* L.) varieties grown in Ethiopia. *International journal of food sciences and nutrition* **56**, 377–387. doi: 10.1080/09637480500512930
- Ahmed, S., Naroz, M., Abdel-Aziz, S., Awad, M. & Abdel-Shafy, S. 2019. Morphological, molecular and biological studies on common bean weevil *Acanthoscelides obtectus* (Say) in Egypt. *Journal of Entomology* **16**, 30–38. doi: 10.3923/je.2019.30.38
- Armenta-López, A.R., Lugo-García, G.A., Sánchez-Soto, B.H., Romero-Félix, C.S., Cortez-Mondaca, E., Nava-Pérez, E. 2021. Resistencia del frijol al ataque del gorgojo pardo *Acanthoscelides obtectus* (Say, 1831) (Coleoptera: Chrysomelidae) en la zona Norte de Sinaloa. *Acta zoológica mexicana* **37**, 1–18. doi: 10.21829/azm.2021.3712427
- Beebe, S. & Corrales, M.P. 1991. Breeding for disease resistance. *Common beans: research for crop improvement* 561–617.
- Bonal, R., Muñoz, A., Aparicio, J.M., Santoro, M. & Espelta, J.M. 2019. Filogeografía, factores históricos y especificidad parásito-hospedador: estudio comparativo de las comunidades de insectos depredadores de bellotas (*Curculio* spp.) en la Península Ibérica y California. *Ecosistemas* **28**(1), 15–25. doi: 10.7818/ECOS.1543
- Cardona, C. & Kornegay, J. 1999. Bean germplasm resources for insect resistance. Global plant genetic resources for insect-resistant crops. CRC Press, Boca Raton:85–99.
- Cardona, C., Kornegay, J., Posso, C.E., Morales, F. & Ramirez, H. 1990 Comparative value of four arcelin variants in the development of dry bean lines resistant to the Mexican bean weevil. *Entomologia Experimentalis et Applicata* **56**, 197–206. doi: 10.1111/j.1570-7458.1990.tb01397.x
- Cardona, C., Posso, C.E., Kornegay, J., Valor, J. & Serrano, M. 1989. Antibiosis effects of wild dry bean accessions on the Mexican bean weevil and the bean weevil (Coleoptera: Bruchidae). *Journal of Economic Entomology* **82**, 310–315. doi: 10.1093/jee/82.1.310
- Cid-Gallegos, M.S., de las Mercedes Gómez, Y., Corzo-Ríos, L.J.C.-R., Sanchez-Chino, X.M., Moguel-Concha, D., Borges-Martínez, E. & Jiménez-Martínez, C. 2023. Potencial nutricional y bioactivo de frijol (*Phaseolus vulgaris*) en la salud humana. *Investigación y Desarrollo en Ciencia y Tecnología de Alimentos* **8**, 309–318. doi: 10.29105/idecyta.v8i1.42
- Espinal, R., Higgins, R. & Wright, V. 2004. Economic Losses Associated with *Zabrotes subfuscintus* (Boheman) (Coleoptera: Bruchidae) and *Acanthoscelides obtectus* (Say) (Coleoptera: Bruchidae) infestations of stored dry red beans (*Phaseolus vulgaris* L.) in Southeastern Honduras. *Ceiba* **45**(2), 107–119.
- FAOSTAT. Statistical Database. In Food and Agriculture Organization of the United Nations; FAO: Rome, Italy. 2022. Available online: <http://faostat.fao.org/> (accessed on 20 May 2023).
- Fory, L., Finardi-Filho, F., Quintero, C., Osborn, T.C., Cardona, C., Chrispeels, M.J. & Mayer, J.E. 1996.  $\alpha$ -Amylase inhibitors in resistance of common beans to the Mexican bean weevil and the bean weevil (Coleoptera: Bruchidae). *Journal of economic entomology* **89**, 204–210. doi: 10.1093/jee/89.1.204

- Gutiérrez-Jirón, X.J. 2016. Manejo de *Acanthoscelides obtectus* (Say) en frijol común (*Phaseolus vulgaris* L.) almacenado utilizando *Bauveria bassiana* (Bals y Vull), Managua, Nicaragua 2016, Universidad Nacional Agraria. <https://repositorio.una.edu.ni/id/eprint/3446>
- Hartweck, L., Cardona, C. & Osborn, T.C. 1997. Bruchid resistance of common bean lines having an altered seed protein composition. *Theoretical and Applied Genetics* **95**, 1018–1123. doi: 10.1007/s001220050656
- Iturralde-García, R.D., Castañé, C., Wong-Corral, F.J. & Riudavets, J. 2020. Biological control of *Acanthoscelides obtectus* and *Zabrotes subfasciatus* in stored dried beans. *BioControl* **65**, 693–701. <https://doi.org/10.1007/s10526-020-10048-5>
- Jiménez-Galindo, J.C., Tortosa, M., Velasco, P., De La Fuente, M., Ordás, B. & Malvar, R.A. 2020. Inheritance and metabolomics of the resistance of two F<sub>2</sub> populations of *Phaseolus* spp. to *Acanthoscelides obtectus*. *Arthropod-Plant Interactions* **14**, 641–651. doi: 10.1007/s11829-020-09776-3
- Jiménez, J.C., de la Fuente, M., Ordás B., Domínguez, L.E.G. & Malvar, R.A. 2017. Resistance categories to *Acanthoscelides obtectus* (Coleoptera: Bruchidae) in Tepary bean (*Phaseolus acutifolius*), new sources of resistance for dry bean (*Phaseolus vulgaris*) breeding. *Crop Protection* **98**, 255–266. <https://doi.org/10.1016/j.cropro.2017.04.011>
- Jones, R. 1987. Behavioural evolution in the cabbage butterfly (*Pieris rapae*). *Oecologia* **72**, 69–76. doi: 10.1007/BF00385047
- Keneni, G., Bekele, E., Getu, E., Imtiaz, M., Damte, T., Mulatu, B. & Dagne, K. 2011. Breeding Food Legumes for Resistance to Storage Insect Pests: Potential and Limitations. *Sustainability* **3**, 1399–1415. <https://doi.org/10.3390/su3091399>
- Kornegay, J., Cardona, C. & Posso, C.E. 1993. Inheritance of resistance to mexican bean weevil in common bean, determined by bioassay and biochemical tests. *Crop Science* **33**, 589–594. <https://doi.org/10.2135/cropsci1993.0011183X003300030034x>
- Kornegay, J.L. & Cardona, C. 1991. Inheritance of resistance to *Acanthoscelides obtectus* in a wild common bean accession crossed to commercial bean cultivars. *Euphytica* **52**, 103–111. doi: 10.1007/BF00021322
- Kusolwa, P. & Myers, J. 2011. Seed storage proteins ARL2 and its variants from the apalocus of wild Tepary bean G40199 confers resistance to *Acanthoscelides obtectus* when expressed in common beans. *African Crop Science Journal* **19**(4), 255–265.
- Lak, F., Zandi-Sohani, N., Ghodoum-Parizipour, M.H. & Ebadollahi, A. 2022. Synergic effects of some plant-derived essential oils and Iranian isolates of entomopathogenic fungus *Metarhizium anisopliae* Sorokin to control *Acanthoscelides obtectus* (Say) (Coleoptera: Chrysomelidae). *Frontiers in Plant Science* **13**, 1075761. doi: 10.3389/fpls.2022.1075761
- Mbogo, K., Davis, J. & Myers, J. 2009. Transfer of the arcelin-phytohaemagglutinin- $\alpha$  amylase inhibitor seed protein locus from Tepary bean (*Phaseolus acutifolius* A. Gray) to common bean (*P. vulgaris* L.). *Biotechnology* **8**, 285–295. doi: 10.3923/biotech.2009.285.295
- Minney, B.H.P., Gatehouse, A.M.R., Dobie, P., Dendy, J., Cardona, C. & Gatehouse, J.A. 1990. Biochemical-bases of seed resistance to *Zabrotes subfasciatus* (bean weevil) in *Phaseolus vulgaris* (common bean) - a mechanism for arcelin toxicity. *Journal of Insect Physiology* **36**(10), 757–761, 763–767. doi: 10.1016/0022-1910(90)90049-L
- Osborn, T.C., Alexander, D.C., Sun, S.S.M., Cardona, C. & Bliss, F.A. 1988. Insecticidal activity and lectin homology of arcelin seed protein. *Science* **240**, 207–210. doi: 10.1126/science.240.4849.207
- Parsons, D.M. & Credland, P.F. 2003. Determinants of oviposition in *Acanthoscelides obtectus*: a nonconformist bruchid. *Physiological Entomology* **28**, 221–231. doi: 10.1046/j.1365-3032.2003.00336.x

- Rodríguez-González, A., Casquero, P.A., Cardoza, R.E. & Gutiérrez, S. 2019. Effect of trichodiene synthase encoding gene expression in *Trichoderma* strains on their effectiveness in the control of *Acanthoscelides obtectus*. *Journal of Stored Products Research* **83**, 275–280. doi: 10.1016/j.jspr.2019.07.006
- Sales, M.P., Gerhardt, I.R., Grossi-de-Sa, M.F. & Xavier, J. 2000. Do legume storage proteins play a role in defending seeds against bruchids? *Plant Physiology* **124**, 515–522. doi: 10.1104/pp.124.2.515
- SAS Institute. Base SAS 9.4 Procedures Guide: Statistical Procedures. Version 9.4; SAS Institute: Cary, NC, USA, 2016.
- Schmale, I., Wackers, F.L., Cardona, C. & Dorn, S. (2003) Combining parasitoids and plant resistance for the control of the bruchid *Acanthoscelides obtectus* in stored beans. *Journal of Stored Products Research* **39**, 401–411. doi: 10.1016/s0022-474x(02)00034-6.
- Schoonhoven A.v., Cardona C.v. & Valor J. 1983. Resistance to the bean weevil and the Mexican bean weevil (Coleoptera: Bruchidae) in noncultivated common bean accessions. *Journal of Economic Entomology* **76**, 1255–1259. doi: 10.1093/jee/76.6.1255
- Shade, R.E., Pratt, R.C. & Pomeroy, M.A. 1987. Development and mortality of the bean weevil, *Acanthoscelides obtectus* (Coleoptera: Bruchidae), on mature seeds of Tepary beans, *Phaseolus acutifolius*, and common beans, *Phaseolus vulgaris*. *Environmental entomology* **16**, 1067–1070. doi: 10.1093/ee/16.5.1067
- Silva, F.B., Monteiro, A.C.S., Del Sarto, R.P., Marra, B.M., Dias, S.C., Figueiraa, E.L.Z., Oliveira, G.R., Rocha, T.L., Souza, D.S.L., da Silva, M.C.M., Franco, O.L. & Grossi-de-Sa, M.F. 2007. Proregion of *Acanthoscelides obtectus* cysteine proteinase: A novel peptide with enhanced selectivity toward endogenous enzymes. *Peptides* **28**, 1292–1298. doi: 10.1016/j.peptides.2007.03.020
- Sword, G. & Chapman, R. 1994. Monophagy in a polyphagous grasshopper, *Schistocerca gossypii*. *Entomologia Experimentalis et Applicata* **73**, 255–264. doi: 10.1111/j.1570-7458.1994.tb01863.x
- Tucić, N., Gliksman, I., Šešlija, D., Milanović, D., Mikuljanac, S. & Stojković, O. 1996. Laboratory evolution of longevity in the bean weevil (*Acanthoscelides obtectus*). *Journal of Evolutionary Biology* **9**, 485–503. doi: 10.1046/j.1420-9101.1996.9040485.x
- Valencia Cataño, S.J. 2006. Efectos subletales de resistencia antibiótica a inmaduros en la demografía de adultos de los gorgojos de frijol *Acanthoscelides obtectus* (Say) y *Zabrotes subfasciatus* (Boheman) (Coleoptera: Bruchidae). Tesis (Ingeniero Agrónomo), Universidad Nacional de Colombia, Facultad de Ciencias Agropecuarias.
- Velten, G., Rott, A.S., Cardona, C. & Dorn, S. 2007. The inhibitory effect of the natural seed storage protein arcelin on the development of *Acanthoscelides obtectus*. *Journal of stored products research* **43**, 550–557. doi: 10.1016/j.jspr.2007.03.005
- Velten, G., Rott, A.S., Petit, B.J.C., Cardona, C. & Dorn, S. 2008. Improved bruchid management through favorable host plant traits and natural enemies. *Biological Control* **47**, 133–140. doi: 10.1016/j.biocontrol.2008.07.009
- Zaugg, I., Magni, C., Panzeri, D., Daminati, M.G., Bollini, R., Benrey, B., Bacher, S. & Sparvoli, F. 2013. QUES, a new *Phaseolus vulgaris* genotype resistant to common bean weevils, contains the Arcelin-8 allele coding for new lectin-related variants. *Theoretical and applied genetics* **126**, 647–661. doi: 10.1007/s00122-012-2008-2