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Boll weevils in dry bolls: is there a performance disadvantage?

COELHO Beatriz S.[1], LEITE Suzany A.[1], SANTOS Mateus P.dos [1], MATES Eloito C.de [1], MORAES Beatriz M. L.de [1], BASTOS Cristina S.[2], GUEDES Raul N. C.[3], MOREIRA Aldenise A.[1] and CASTELLANI Maria A.[1,4*]

Abstract

Background *Anthonomus grandis grandis* is the main cotton pest in the Americas, with the potential to become a pest in other continents. The insect uses the plant's reproductive organs for feeding, oviposition, and survival strategies in the off-season, sheltering in dry bolls. This study aimed to know the reproductive potential, feeding, longevity, and morphometric characteristics of boll weevils from dry bolls, squares, and traps. Adults were obtained from infested squares, dry bolls, and traps installed in cotton fields and the Caatinga area. Thirty weevil pairs were maintained in the laboratory to assess the oviposition, feeding holes, longevity, and morphometric measurements of the parental and F_1 generations.

Results In the parental generation, boll weevils from traps (the Caatinga area and cotton cultivation) showed greater reproductive potential. Boll weevils from squares and the Caatinga area showed greater feeding activity compared with those from cotton cultivation. Greater rostrum length, thorax + abdomen length, and abdomen width were observed in boll weevils from cotton cultivation and dry bolls. The origin of boll weevils parental generation did not affect progeny emergence time. The F_1 generation of boll weevils showed significant differences in average longevity depending on the origin of different microhabitats. Furthermore, differences in rostrum lengths were observed, with the boll weevils coming from traps installed in cotton cultivation, the Caatinga area, and dry bolls being the largest. Regarding thorax + abdomen length and abdomen width, the highest values were observed in those from the Caatinga area and cotton cultivation.

Conclusion It was proven that dry bolls did not affect the reproductive, feeding, and longevity performance of boll weevils, enabling better insect fitness (reproduction and size) in relation to those coming from squares. The use of dry bolls as off-season shelter is an important survival strategy for the boll weevil.

Keywords *Anthonomus grandis grandis*, *Gossypium hirsutum*, Off-season, Survival

Introduction

The boll weevil *Anthonomus grandis grandis* Boheman (Coleoptera: Curculionidae) is the main cotton pest in the Americas (Azambuja et al., 2014; Arruda et al., 2021). The injury is caused by adults, which feed on and lay their eggs in reproductive structures; and by larvae, which develop inside the attacked structures, causing the shedding of infested flowers, floral buds, and young bolls, reduction of the production and quality of the fiber .(Santos et al., 2003; Showler, 2006; Ribeiro et al., 2017). Various factors can affect the boll weevil population dynamics, including

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*Correspondence:
Castellani Maria A.
castellani@uesb.edu.br
[1] Departamento de Fitotecnia e Zootecnia, Universidade Estadual do Sudoeste da Bahia, Vitória da Conquista, BA 45031-900, Brazil
[2] Faculdade de Agronomia e Veterinária, Universidade de Brasília, Brasília, DF 70910-900, Brazil
[3] Departamento de Entomologia, Universidade Federal de Viçosa, Viçosa, MG 36570-900, Brazil
[4] Pós-Graduação em Agronomia (Fitotecnia), Universidade Estadual do Sudoeste da Bahia, Vitória da Conquista, BA 45031-900, Brazil

climate variations, availability of food resources, and individual intrinsic factors, such as age, reproductive status, and previous mating (Ramalho et al., 1996; Arruda et al., 2021). Boll weevil is a multivoltine insect and has a high capacity for dispersion, adaptation, and use of multiple food sources (Macêdo et al., 2015; Salvador et al., 2021). These characteristics allow to increase in the incidence, density, and geographic distribution of the pest (Pimenta et al., 2016; Ribeiro et al., 2020a). The cotton ecosystem in Brazil is highly favorable to the development of boll weevils, with a suitable climate for the growing season and the availability of food sources (Torres et al., 2022).

The wide diversity of landscapes found in the tropics provide a range of environmental options that may explain the persistence of boll weevil populations in subsequent cotton-growing seasons (Pimenta et al., 2016). Adult boll weevils migrate to refuge areas (e.g., grasslands, forests, and native vegetation) in subtropical regions, especially areas with a predominance of the Caatinga and Cerrado vegetation, at the end of the cotton crop season (Degrande, 1991; Gondim et al., 2001). In these areas, they commonly feed on pollen grains from different plant species (Showler, 2009; Macêdo et al., 2015; Pires et al., 2017).

This insect also lodges and develops during the off-season in structures known as dry bolls, which are dry and malformed cotton fruits containing agglomerated fibers (Showler, 2007). However, there are still many gaps in knowledge about the emergence and survival dynamics of boll weevils that shelter in these structures (Do Vale et al., 2021). Live boll weevils were found in dry bolls 135 days after cotton harvest in Bahia, Brazil; enough time to survive the health vacuum period established by the state, which is 60 days (Ribeiro et al., 2020b). This fact justifies the importance of adequate destruction of cotton crop residues, as structures like dry bolls, infested by the boll weevil, can remain intact in the off-season environment, enabling the emergence and dispersion of the insect to refuge areas (Ribeiro et al, 2015).

Over the last few years, the accumulated knowledge regarding the off-season survival of the boll weevil is still not enough to fully explain the high populations of the pests observed at the beginning of subsequent growing seasons. It is a fact that the boll weevil can stay alive in dry bolls but the reproductive capacity following the departure of adults from these structures has not yet been fully elucidated. Thus, it is essential to know the importance of dry bolls in the maintenance and population increase of the pest in subsequent crops.

Knowledge about the reproductive abilities, feeding potential, longevity, and morphometry of boll weevils that originate and live in different microhabitats, can determine the patterns of survival, emergence, and reproduction of this pest. Understanding these phenomena can assist in adapting and guiding the ideal times for carrying out insecticide spraying and the adoption of effective and alternative techniques for pest management, beyond the chemical control.

The body size of an insect is an indication of good availability of energy and nutrient reserves for the various physiological processes of the species and aptitude for reproduction (Thorne et al., 2006). Thus, morphometric studies play a key role in understanding the strategies adopted for pest survival. In general, female boll weevils are larger due to their greater biological demands compared with males (Santos et al., 2021). Females of the Curculionidae family also have differences in their faces, which are larger and flatter when compared with males (Soto et al., 2014), which should facilitate the feeding process. Feeding based on pollen from cotton squares allows boll weevils to have larger body sizes and increased reproduction and oviposition rates when compared with the use of other structures such as bolls (Showler, 2004).

The hypothesis is that dry bolls are structures that allow the survival of adult boll weevils without affecting their reproductive, feeding, and survival potential when compared with those originating from other plant organs used for larval development and feeding.

Thus, this study aimed to assess the reproductive and feeding potentials, as well as the longevity and morphometric characteristics (size and shape) of adult boll weevils from dry bolls, squares, and pheromone traps in cotton cultivation and Caatinga area. This information can provide important knowledge for improving boll weevil management programs in cotton cultivation systems and for implementing control measures that hinder the pest's survival during the off-season.

Materials and methods

Insect collection

Adult boll weevils and cotton reproductive structures with signs of oviposition were collected from commercial cotton fields (15 km away), located in the municipality of Iuiu, in the southwest region of the state of Bahia, Brazil. The cotton variety TMG 47 B2RF was used in these fields. The collection of squares was carried out in a cultivation area (coordinates −14°25′75.0″ S and −43°48 56′53.2″ W) during the third square stage (B_3), approximately 30 days after emergence (DAE); while the collection of dry bolls and the trap installation were conducted in areas of cotton cultivation and Caatinga area (coordinates −14°19′10.0″ S and −43°30′30.2″ W) during the second white flower stage (F_2) , approximately 60 DAE, collected at the end of the production cycle.

Bioassays and experimental design

The experimental design was completely randomized, with four treatments and 30 replications. Each treatment consisted of 30 boll weevil pairs from the following microhabitats: (1) cotton squares, (2) dry boll (dry and malformed structure); and (3) ten pheromone traps positioned in cotton cultivation fields, and (4) Caatinga area. Squares were randomly collected from the middle third of the plants and placed in plastic trays covered with voile fabric until adults emerged. A similar procedure was followed for the dry bolls, with a light dissection to facilitate the emergence of adult insects.

Fluorescent green boll weevil Accountrap® were installed on a pole 1 m above the ground with the pheromone traps Luretape BW-10, which were exposed for 24 hours to collect adult boll weevils in the cotton growing area and Caatinga area (Ribeiro et al., 2010). In each area (3 and 4), 20 traps were evenly distributed along two 100-m long lines spaced 10 meters apart. In the cotton cultivation fields, traps were placed about 40 m away from the planting border. In Caatinga area, the traps were installed along the border of the forest. The adults obtained from the traps were placed in plastic containers with squares for feeding and cotton moistened with water for hydration.

The squares, dry bolls, and adults were placed in a polystyrene box and transported to the laboratory. They were conditioned in a biochemistry oxygen demand oven set at a temperature of 25 °C, relative humidity of 70%, and a photophase of 10 h.

Sexing was carried out after obtaining the adults (parental generation) from the respective microhabitats by placing the boll weevils in petri dishes (140×15 mm) and, after mating (male over female), following the methodology proposed by Grossman (1929). The weevil pairs were individualized and placed in plastic containers (50 mL) covered with voile fabric containing cotton moistened with distilled water and cotton squares (free from feeding and oviposition, holes collected in cultivated cotton of the FM 975WS variety without the use of insecticides). The containers containing the weevil pairs (parental generation) were placed in a climate-controlled room at (23±2) °C and (60±10)% relative humidity. One square of 6 to 8 mm in diameter was selected to be offered to the weevil pairs (Michelotto et al., 2007). The squares were changed every three days to count the number of oviposition and feeding holes. Subsequently, the squares were individualized, identified, and transferred to other containers containing cotton moistened with distilled water until the emergence of adults of the F_1 generation.

Morphometric analyses

Linear measurements of the rostrum length, thorax + abdomen length, and abdomen width of the parental and F_1 generations were taken after the death of the boll weevils, without distinguishing the sex, following the methodology proposed by Santos et al. (2021), with adaptations. The boll weevils of each treatment were placed on a slide and photographed by a Leica MC 170 HD digital camera coupled to a Leica S8 APO stereo microscope (Wetzlar, Germany) at 80× magnification in the upper lateral view, always at the same distance. The images were exported to JPEG files using the Leica Application Suite v. 3.8.0 software (Leica Microsystems Limited, Switzerland).

The acquired images were compiled using the tpsUtil v. 1.78 package (Rohlf, 2018). Then, 1 landmark and 7 anatomical semi-landmarks were digitized (Köelliker-Ott et al., 2003) using the tpsDig2 v. 2.31 software (Rohlf, 2017) for morphometric analysis of the rostrum shape. The X-Y coordinates were determined from the added semi-landmarks. The procrustes superimposition was performed by arranging the semi-landmarks in the same size, position, and orientation to obtain data on the shape of the rostrum (Klingenberg, 2011).

The measurement of the size of the rostrum was determined by the centroid size (CS) (μm), calculated by the square root of the sum of the squares of the distances between semi-landmarks, using the mean of the determined X-Y coordinates (Bookstein, 1991). Significant variables were selected based on Akaike´s information criterion (AIC). Morphometric analyses were performed using the MorphoJ v. 1.06d software (Klingenberg, 2011). PCA (principal component analysis) was performed using R v. 3.6.1 software (R Development Core Team, 2019), applying the selected variables to transform data from a wide spectrum to a low spectrum space.

Statistical analyses

Oviposition, feeding, survival, and centroid size data were subjected to analysis of variance using generalized linear models (GLM), the model with distribution Gaussian, implemented in R v. 3.6.1 software (R Development Core Team, 2019). The linear dimensions (size) data of the insects were subjected to the *F*-test and the means were compared by the Tukey test at a significance level of 1% using the Sisvar software.

The shape of the rostra was compared using the canonical correlation analysis (CCA) and its significance was determined by the permutation test with 10 000 iterations ($P < 0.05$) in the MorphoJ software. CCA allows the discrimination of groups with variations close to each other. The cluster analysis was applied to define which populations presented similarities between themselves, regarding the shape of the rostrum.

Results

Reproductive and feeding potentials

Reproductive potential of boll weevils was affected by different microhabitats during their development

(Fig. 1A). Boll weevils (parental generation) from cotton cultivation fields ($\dot{x}$ = 0.892, SE = 0.040, $P < 0.05$) laid more eggs than those from Caatinga area ($\dot{x}$ = 0.730), dry bolls ($\dot{x}$ = 0.409), and squares ($\dot{x}$ = 0.189). All weevil pairs evaluated carried out at least one oviposition during the observation period. The highest number of feeding holes was observed for boll weevils obtained from squares ($\dot{x}$ = 6.750; SE = 0.328; $P < 0.05$) and Caatinga area ($\dot{x}$ = 6.310). However, boll weevils originating from cotton cultivation fields ($\dot{x}$ = 5.000) and dry boll ($\dot{x}$ = 5.550) presented the lowest number of feeding holes when compared with those from squares (Fig. 1B).

Longevity and progeny emergence time of boll weevils

The longevity of F_1 generation boll weevils varied according to the type of microhabitats used during their development (Fig. 1C). Descendants of boll weevils from dry bolls had higher longevity ($\dot{x}$ = 38.4 days, Lim_{max}: 41.9 days, SE = 1.789, $P < 0.05$) than those from Caatinga area ($\dot{x}$ = 28.5 days, Lim_{max}: 30.3 days, SE = 0.929, $P < 0.05$),

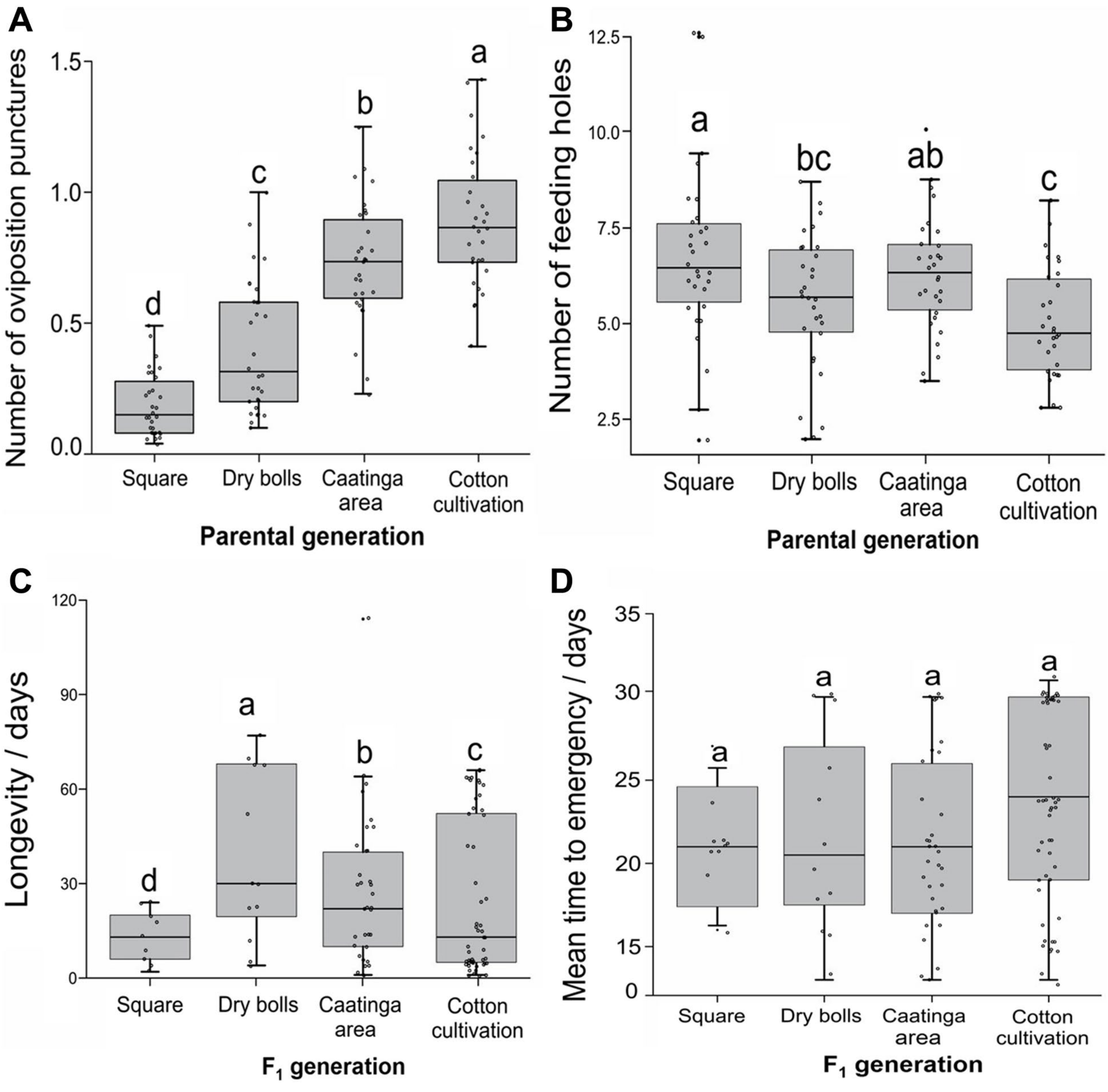

Fig. 1 Mean number of oviposition holes (**A**), feeding potential (**B**), longevity (days) of F_1 generation (**C**), time (days) for emergence (egg to adult stages) (**D**) of adult boll weevils from squares, dry bolls, Caatinga area, and cotton cultivation fields. Boxes with the same letter are not significantly different (GLM, Gaussian distribution, $P < 0.05$)

cotton cultivation fields ($\dot{x}$ = 24.7 days, Lim_{max}: 26 days, SE = 0.689, $P < 0.05$), and squares ($\dot{x}$ = 13.3 days, Lim_{max}: 15.7 days, SE = 1.217; $P < 0.05$).

The mean time for progeny emergence (days the insect took to leave the squares) did not differ among treatments (Fig. 1D). Regardless of the origin of the adult boll weevils, their descendants exhibited the same development period to reach the adult stage (egg to adult stages), averaging 21 days.

Morphometry

The rostrum length varied according to the microhabitat of origin. In the parental generation (Fig. 2A), insects collected from traps installed in cotton cultivation fields ($\dot{x}$ = 0.209 cm, SE = 0.002, $P < 0.05$) and dry bolls ($\dot{x}$ = 0.212 cm) showed the longest rostrum. Similar rostrum lengths to insects from squares ($\dot{x}$ = 0.203 cm) and Caatinga area ($\dot{x}$ = 0.203 cm) were observed.

In the F_1 generation (Fig. 2B), boll weevils from cotton cultivation fields ($\dot{x}$ = 0.206 cm, SE = 0.006, $P < 0.05$), Caatinga area ($\dot{x}$ = 0.206 cm), and dry bolls ($\dot{x}$ = 0.212 cm) had the longest rostrum.

Boll weevils from traps installed in cotton cultivation fields ($\dot{x}$ = 0.517 cm, SE = 0.005, $P < 0.05$) and dry bolls ($\dot{x}$ = 0.501 cm) of the parental generation showed longer thorax + abdomen (Fig. 2C). Similar lengths were verified for insects from dry bolls and Caatinga area ($\dot{x}$ = 0.487 cm). The shorter thorax + abdomen were observed for boll weevils originating from squares ($\dot{x}$ = 0.480 cm). Regarding the F_1 generation, insects from traps installed in Caatinga area ($\dot{x}$ = 0.508 cm, SE =0.015, $P < 0.05$) and cotton cultivation fields ($\dot{x}$ = 0.504 cm) presented longest thorax + abdomen (Fig. 2D).

Boll weevils from dry bolls ($\dot{x}$ = 0.228 cm; SE = 0.002; $P < 0.05$) and traps installed in cotton cultivation fields ($\dot{x}$ = 0.226 cm) presented wider abdomen (Fig. 2E). The F_1 generation of boll weevils collected in traps installed in Caatinga area ($\dot{x}$ = 0.227 cm) and cotton cultivation fields ($\dot{x}$ = 0.219 cm) showed wider abdomen (Fig. 2F).

Significant differences were found for the CS of the rostrum (GLM, AIC: 292.05, $P < 0.005$) (Fig. 3). The mean size of the rostrum centroid for boll weevils from traps installed in cotton cultivation fields and dry bolls were 1 545 and 1 538 μm, respectively, which were higher than means obtained for those from squares (1 457 μm) and traps in Caatinga area (1 453 μm).

The three canonical correlations explained 100% of the variation in the shape of the rostrum of boll weevils from different microhabitats. The first canonical axis explained 70.17% of the variation, the second explained 18.17%, and the third explained 11.66% (Fig. 4). The results of the canonical correlation analysis showed maximal variations in the shape of the rostrum between populations (Fig. 4). Boll weevils from squares and dry bolls had less dispersion of scores from each other, showing the highest similarity in the shape of the rostrum. In contrast, those from Caatinga area and cotton cultivation fields had higher dispersion of scores, indicating higher differences in the pattern of the shape of the rostrum (Fig. 4).

Changes in the shape of the rostrum were observed along the CV1 axis at landmarks and semi-landmarks 1, 2, 3, and 4, while changes along the CV2 axis could be observed at landmarks and semi-landmarks 1, 3, 6, and 8 (Fig. 5A). The cross-validation test showed an average of 64.84% correct classification of the specimens (Table 1). The Mahalanobis distances revealed a significant difference between groups, ranging from 1.001 5 (cotton cultivation fields×dry boll) to 1.880 1 (cotton cultivation fields×Caatinga area) (Table 2).

The greatest similarity in the shape of the rostrum was observed in boll weevils from squares and dry bolls forming groups of these two populations with those from cotton cultivation fields (Fig. 5B). Insects from Caatinga area grouped together but distanced themselves from other microhabitats, indicating higher separation (difference) in the shape of the rostrum of these individuals.

Discussion

Oviposition behavior can influence population dynamics through the variation of spatial and temporal deposition of eggs in the host (Greenberg et al., 2003). Thus, knowledge about the reproductive potential of boll weevils can be useful in making informed decisions regarding control methods in cotton and understanding its dynamics.

Variations in insect body size can affect reproduction, dispersal capacity, and intraspecific competition (Foelker et al., 2014). In addition, body size often correlated with parameters of the insect's life history, such as egg number and size, fecundity, female attractiveness, adult longevity, reproductive longevity, progeny emergence, egg viability, and pupae and larvae mass (Sagarra et al., 2001), thus influencing their performance in the environment. The joint impact of these effects, as they are multiplicative, tends to affect the population growth of this pest (Greenberg et al., 2005). This study showed that smaller body sizes of boll weevils from cotton squares may have impacted the reproductive potential and longevity of these individuals, which consistent with previous research. Despite the squares being the preferred structures feeding boll weevils (Ramalho et al., 1988), individuals emerging from squares do not show improved performance regarding reproduction, progeny longevity, longer rostrum and thorax + abdomen, and wider abdomen (parental generation) compared with individuals from dry bolls.

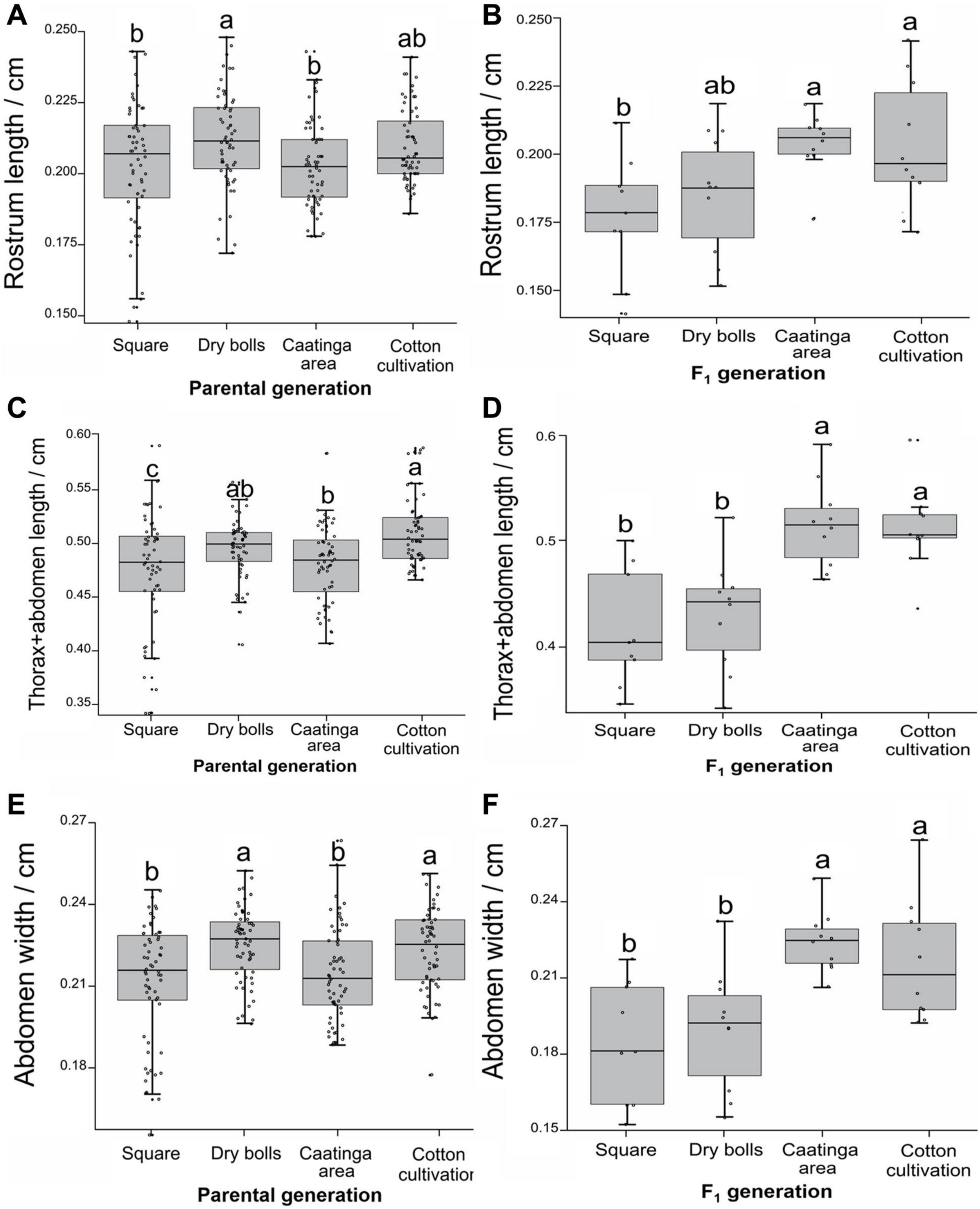

Fig. 2 Mean rostrum length of parental (**A**) and F_1 generations (**B**), thorax + abdomen length of parental (**C**) and F_1 generations (**D**), abdomen width of parental (**E**) and F_1 generations (**F**) of adult weevils from squares, dry bolls , Caatinga area, and cotton cultivation fields. Boxes with the same letter are not significantly different (GLM, Gaussian distribution, $P < 0.05$)

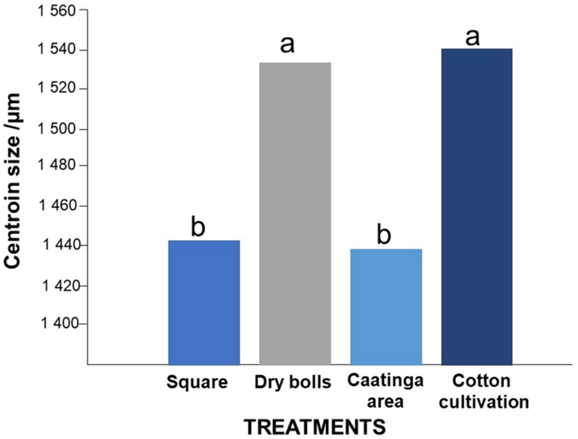

Fig. 3 Centroid size (CS) of adult boll weevils from squares, dry bolls, Caatinga area, and cotton cultivation fields. Bars with the same letter do not show significant differences from each other [GLM, SEM= 87.46, AIC = 292.05, $P < 0.05$ (Gaussian family (link = identity)]. Bars represent average values

Pollen from many plant species is ingested by boll weevils, but pollen-free food sources are also ingested, including cotton leaves and petioles (Showler et al., 2007). The ingestion of other structures can contribute to an improvement in the reproductive performance and longevity in these individuals. Alterations in the vegetative stage of cotton promote changes in the feeding pattern of boll weevil. In addition, feeding on different parts of the cotton plant influences the biology and ecology of this pest (Showler, 2008).

Thus, the decline in the reproductive abilities of individuals from squares compared with those from dry bolls may be associated with the fact that boll weevils use dry bolls for food and housing at the end of the crop cycle, thereby favoring their permanence in the subsequent growing season (Macêdo et al., 2015). These insects usually store energy at the end of the crop cycle to meet the development needs of their reproductive system (Paula et al., 2013). This pattern is associated with the phenology of the cotton plant and can be considered the main adaptive strategy of boll weevils to survive off-season periods (Pires et al., 2017). The limited space and lack of food inside dry bolls make it difficult for boll weevils to survive for a long period (Ribeiro et al., 2015). The descendants (F_1 generation) of boll weevils from dry bolls showed longer longevity compared with those from other microhabitats. The offspring of parents living under unfavorable conditions have better aptitudes than the offspring of parents maintained under natural or favorable conditions, as the adjustments of the parental generation are transmitted to the offspring to make them able to face challenging circumstances (Amiria et al., 2021). Therefore, the descendants from dry bolls could survive longer in crops in the initial period of the subsequent cotton growing season in high population levels, generating higher difficulties in controlling the pest at the early stages of crop development. This result reinforces the importance of the correct destruction of dry bolls, since adults are capable of re-establishing themselves in new plantations at any time when they leave these structures (Paula et al., 2013; Ribeiro et al., 2015).

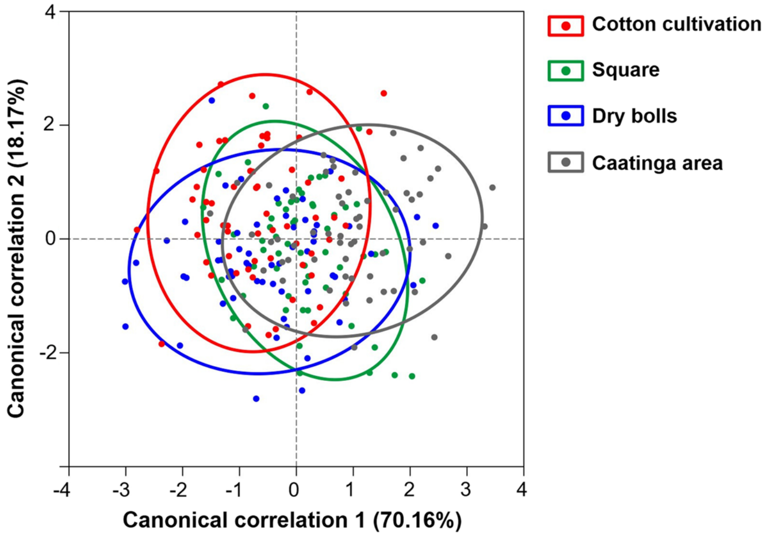

Fig. 4 Plot representing the variation in the shape of the rostrum among adult weevils from squares, dry bolls, Caatinga area, and cotton cultivation fields along the first two axes of canonical correlation (CC1 and CC2) with 90% confidence ellipse

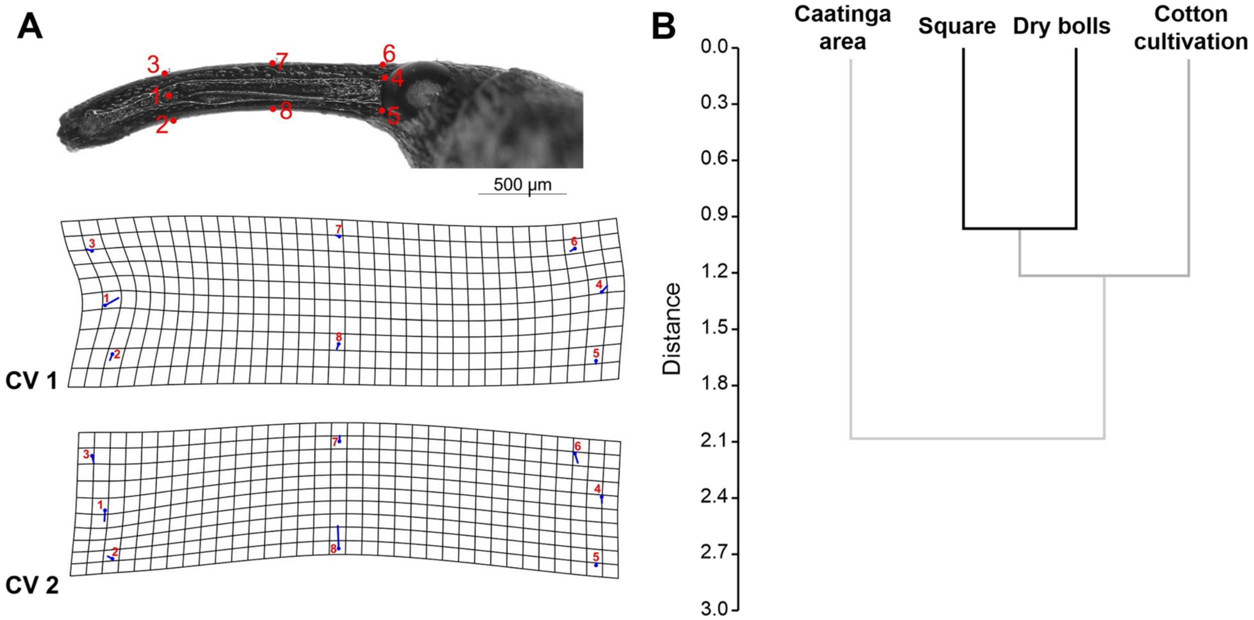

Fig. 5 Deformation grids illustrate shape changes along the CV1 and CV2 axes in positive directions. Circles represent the anatomical landmarks and semi-landmarks, and sticks indicate the changes relative to the landmarks and semi-landmarks (**A**), cluster analysis demonstrates the relationship between the shape of the rostrum among populations of boll weevils, based on the Mahalanobis distances of the rostrum of adult weevils from dry bolls, squares, Caatinga area, and cotton cultivation fields (**B**)

Table 1 Cross-validation test. Percentage of regions of the rostrum of boll weevils allocated correctly by treatment according to rostrum shape

	Square	Dry boll	Caatinga area	Cotton cultivation fields
Square	-	-	-	-
Dry boll	59.66	-	-	-
Caatinga area	60.54	69.17	-	-
Cotton cultivation fields	63.04	61.67	75.00	-

Table 2 Mahalanobis distance between groups (lower left side) and *P*-value of the permutation test (10 000 iterations) (upper right side) among different boll weevils populations

	Cotton cultivation fields	Square	Dry boll	Caatinga area
Cotton cultivation fields	-	0.004 9	0.013 0	<0.000 1
Square	1.218 8	-	0.005 8	0.000 4
Dry boll	1.001 5	1.059 6	-	<0.000 1
Caatinga area	1.880 1	1.212 7	1.419 7	-

Boll weevils from the parental generation collected from Caatinga area exhibited smaller rostrum sizes, thorax + abdomen length and abdomen width. In the Caatinga area, boll weevils tend to have a smaller body size as food sources are limited and environmental stress is high, which can be beneficial, allowing them to be more resistant to food shortages and high temperatures (Santos et al., 2021). The biggest alterations in the shape of the rostrum of boll weevils from Caatinga area are possibly due to the need for these insects to seek alternative sources of food. Changes in the body shape (asymmetry) of an insect due to a condition of environmental stress reveal that organisms are constantly exposed to a changing environment whether through changes in diet, temperature, predators, competitors, or all these factors simultaneously (Benitez et al., 2020). Boll weevils from Caatinga area in Bahia exploit alternative food sources during the off-season in 16 botanical families, such as Fabaceae, Solanaceae, Poaceae, and Euphorbiaceae (Macêdo et al., 2015).

The highest reproductive potential (parental generation), rostrum length and thorax + abdomen length, and abdominal widths (parental and F_1 generations) were found in boll weevils from cotton cultivation fields. It is related to the fact that these insects have developed in a microhabitat with high food availability, thus having essential nutrients for their development, high nutritional reserves, and, consequently, better reproductive performances.

The biological cycle of insects is affected by the food quality, which includes carbohydrate, vitamin, and protein composition, and may influence their longevity, development, and fecundity (Silveira-Neto et al., 1976). Individuals adapted to environments with high nutritional food sources generally have larger body sizes and better performances than individuals with inadequate nutrition (Parker et al., 2009; Berger et al., 2012). Environmental factors, such as temperature and habitat, can alter insect body size and influence reproductive potential. It is important to highlight that the fertility potential of female insects is directly related to their body size (Honěk, 1993).

The boll weevil has its body size, reproduction, and longevity affected depending on the type of reproductive structure used in larval development and feeding. Understanding these factors may support the improvement of technical recommendations on the management of this pest during the off-season, expanding the ability to identify the aptitudes of boll weevil populations as a function of their multiple survival microhabitats. The results prove that dry bolls do not affect the reproductive, feeding, and longevity performance of boll weevils, allowing superiority of some insect quality indicators (e.g., reproduction and size) compared with those coming from squares. The use of dry bolls as the off-season shelter is an important survival strategy for boll weevils. Cultural management that considers the destruction of these structures after the cotton harvest should be taken into account within an integrated pest management program.

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Authors' contributions

Coelho BS: Conceptualization, data curation, formal analysis, investigation, methodology, validation, visualization, writing – original draft, writing – review and editing. Leite SA: Data curation, formal analysis, methodology, visualization, writing – original draft, writing – review and editing. Santos MP dos: Data curation, formal analysis. Mates EC de: Data curation, formal analysis. Moraes BML de: Investigation, methodology. Bastos CS: Conceptualization, methodology, validation, visualization, writing – review and editing. Guedes RNC: Conceptualization, validation, visualization, writing – review and editing. Moreira AA: Conceptualization, methodology, validation, visualization, writing – review and editing. Castellani MA: Funding acquisition, writing – original draft, supervision, resources.

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Availability of data and materials

Not applicable.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this article.

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