Article

Agroecological management of *Macrodactylus nigripes* (Coleoptera: Melolonthidae) in corn

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Abstract

Macrodactylus nigripes (Bates) is a pest that attacks corn crops, causing economic losses in production. In order to find agroecological alternatives for its management, the objective was to evaluate the effect of the application of *Argemone mexicana* L., *Ricinus communis* L, *Beauveria bassiana* (Bals) Vuill and *Metharrizium anisoplae* (Metschnikoff) Sorokin, as well as the collection of *M. nigripes* with a beating net in corn crops. The experiment was conducted under a completely randomized block design with four repetitions, where the five control methods were tested and compared with the control treatment (water). *R. communis* and *A. mexicana* significantly decreased plant infestation by *M. nigripes*, increasing production by 36% and 30%, respectively. These results show that both treatments alternated with zote soap can be a good alternative for the management of this pest species.

Keywords: entomopathogenic fungi, foliage pests, plant extracts.

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Introduction

Corn (*Zea mays* L.) is one of the most important agricultural crops in Mexico in the food, political, economic and social fields (Ruíz-Torres *et al*., 2012). Its extension in Mexico represents 30% of agricultural production and 6.6% of the country's arable land (SAGARPA, 2017). Puebla is among the eight main corn-producing states, with a cultivation area of 525 108 ha, representing 7% of the area harvested nationally (López *et al*., 2020), calculating around 994 thousand ha devoted to agriculture, of which 60.1% is used for sowing corn, mostly for self-consumption and 34% for livestock feed (García and Ramírez, 2012).

One of the main factors contributing to the decrease in yields in the production of this crop in the region is the attack of pest insects (Lugo-García *et al*., 2012; Huerta *et al*., 2014; SAGARPA, 2017). Among the most economically important that cause losses in production are the grasshopper *Sphenarium purpurascens*, Mexican corn rootworm *Diabrotica* spp., corn earworm *Helicoverpa zea* (Boddie), beet armyworm *Spodoptera exigua* (Hübner) and fall armyworm *Spodoptera frugiperda* (J. E. Smith) (Aragón *et al*., 2001; Santos *et al*., 2003; Lugo-García *et al*., 2012; Rangel *et al*., 2014; Tulli *et al*., 2015) and chafer *Macrodactylus nigripes* (Bates), standing out as an important pest for the corn crop, decreasing its yields between 20 to 70% (Arce-Pérez and Morón, 2000; Caselín *et al*., 2003).

The larvae of these beetles can cause damage to the root system of the plant by feeding on it, while adults feed on the foliage and inflorescences of corn during the months of May to September, preventing the formation of grain (Altieri and Trujillo, 1987; Hernández *et al*., 1993). The control of *M. nigripes* is mainly based on the use of chemical insecticides such as carbamates and organophosphates, it is estimated that about 3 000 t of insecticides is applied every year, which, far from solving the problem, have increased it, resulting in the elimination of natural enemies, environmental pollution and the resistance of insects to this type of compounds (Wise *et al*., 2002; Blanco *et al*., 2014).

From the agroecological point of view, pest management includes a set of cultural or biological techniques that can minimize the use of chemical pesticides (Arauz, 1997). The use of plant extracts, entomopathogenic fungi and physical methods represent an option to the replacement of chemical insecticides, because they do not have a prolonged residual effect on the environment, are low cost and easy to use for producers (Vázquez *et al*., 2016).

The castor oil plant *Ricinus communis* L. (Euphorbiaceae) has a high insecticidal activity against various insects, such as the yellow sorghum aphid (*Melanophis sacchari* Zehntner), mosquito larva *Culex*, whitefly (*Bermisia tabaco* L.), Indian meal moth (*Plodia interpunctella* Hubner), agave weevil (*Scyphophorus acupunctatus* Gyllenhal) and fall armyworm (*S. frugiperda*) (Collavino *et al*., 2006; Pacheco, 2009; Corradine *et al*., 2014; Guevara *et al*., 2015), due to the presence of secondary metabolites such as ricin and ricinine (Rauer *et al*., 2012), which are found in high concentrations, mainly in seeds (Pita *et al*., 2004).

While Mexican prickly poppy (*Argemone mexicana* L.) has alkaloids such as protopine and berberine found in foliage, as well as flavonoids in flowers and seeds (Fernández-Calienes *et al*., 2016), which are used for their insecticidal properties against various insects such as pear blight beetles (*Xyleborus dispar* Fabricius), (*Scolytus rugulosus* Muller), grasshopper (*Sphenarium purpurascens* Charp), red cotton bug (*Dysdercus koenigii* Fabricius), oriental leafworm moth (*Spodoptera litura* Fabricius) and corn weevil (*Sitophilus oryzae* L.) (Carrillo-Rodríguez *et al*., 2011; Rodríguez-Flores *et al*., 2012; Vázquez *et al*., 2016; Ali *et al*., 2019; Vetal and Pardeshi, 2019).

With regard to the entomopathogenic fungus *Beauveria bassiana* (Bals) Vuill, it can harm more than 200 species of insects, including pests of great agricultural importance such as: the coffee berry borer *Hypothenemus hampei* (Ferrari), cabbage moth *Plutella xylostella* L. and the banana weevil *Cosmopolites sordidus* G. (Alean, 2004).

Metarhizium anisopliae (Metschnikoff.) naturally attacks more than 300 species of insects belonging to different orders, mainly Coleoptera and Hemiptera. Currently there are several studies where the susceptibility of coleopterans to this type of fungi is reported, on this, Nájera-Rincón *et al*. (2005) mention that the genus *Phyllophaga* (Coleoptera: Melolonthidae) can lead to a mortality of 49% under the effect of *B. bassiana* and up to 80% with *M. anisopliae*. Similarly, Almeida *et al*. (2005) report that, at different concentrations, *B. bassiana* causes a mortality of 96.7, 83.4 and 91.1%, respectively, on eggs, larvae and adults of *Anthonomus grandis* (Boheman) (Coleoptera: Curculionidae).

Based on the above, the objective was to evaluate the effect of the use of plant extracts of castor oil plant and Mexican prickly poppy, as well as the entomopathogenic fungi *B. bassiana* and *M. anisoplae* against *M. nigripes* and the manual collection of chafers as alternatives for the agroecological management of the corn crop in the municipality of Huejotzingo, Puebla.

Materials and methods

The experimental work was carried out in the 2017 agricultural cycle, in a rainfed plot located at the geographical coordinates 19° 10’ 30” north latitude and 98° 24’ 36” west longitude, with an altitude of 2 272 masl. The agricultural work of soil preparation for the cultivation of corn consisted of fallow, harrowing and furrowing, a white corn hybrid, Euros, was sown, the distance between furrows was 70 cm and between plants was 30 cm, the experimental plot had a total area of 1 625 m^2.

The treatments that were evaluated are shown in Table 1, alternated with the applications of bar soap (zote). The experiment was established under a randomized complete block design, with six treatments and four repetitions. The experimental unit consisted of 24 corn plants and the useful plot was made up of eight central plants.

To evaluate the effect of *A. mexicana*, foliage, flower and seed of the plant were used, while for *R. communis*, it was made with the mature fruit of the plant. To obtain the plant extracts, the methodology proposed by Pérez-Torres *et al*. (2017) was followed, which consists of collecting these plants during March, April and May in the same locality of the study area, which were left to dry in the shade on kraft paper for 30 days, every third day the plant is turned to avoid the arrival of microorganisms that may damage it, then it is ground with an electric grinder for grain of the Nixtamatic brand, until obtaining a fine powder. The material was labeled and packed in raffia bags to be stored in a cool, dry place until the day of use.

Table 1. Treatments used for the management of *M. nigripes* in the corn crop.

Number	Treatment	Concentration (%)	Part of the plant used
1	*R. communis*	3	Seed
2	*A. mexicana*	3	Foliage, flower and seed
3	*B. bassiana*	1.1^{10}	-
4	*M. anisopliae*	1.1^{10}	-
5	Collection with a beating net		-
6	Control (water)		-

The plants extracts were prepared one day before each application by weighing 30 g of plant material per liter of water, throughout the experiment, it was left to stand for 24 h in order to extract the water-soluble compounds from the plant, then filtered with a fine mesh (tricot fabric) to separate the solids from the liquids, the concentrate obtained was diluted in 16 L of water and applied with a backpack sprayer, these applications were alternated with bar soap, previously grated and dissolved in water, 24 h before use, at a dose of 100 g per 16 L of water throughout the experiment. The applications were made weekly, so that one week the aqueous extract of the plant was applied and the other the soap, making a total of six applications (three of the extract and three of soap).

The entomopathogenic fungi used, *B. bassiana* and *M. anisoplae*, were obtained separately commercially (Organic Vel), the concentration was 1 x 10^{10} spores per gram of the product and a viability of six months. Thirty grams of each product were diluted in 16 L of water. Applications were made every 15 days, with a total of four applications. All applications were made with a backpack sprayer of 16 L capacity, throughout the phenology of the crop until flowering and in the initial phase of the appearance of *M. nigripes*. With respect to the treatment where the insects were collected, this was carried out every week, the collections of the organisms were carried out by means of a beating net of 30 cm in diameter, which was passed around the corn plants.

The variables evaluated were, number of infested plants, which was quantified every week before the application of each treatment, making a total of six evaluations, for this the eight plants of the useful plot were considered as 100% and the number of plants where the presence of *M. nigripes* was found and the production for each treatment mentioned above at the end of the crop cycle were counted, once the harvest was done, the seed was cleaned and weighed on a triple beam balance (Ohaus triple beam mechanical 2 610 g), obtaining the weight in kilograms per useful plot of each treatment; to later extrapolate to t ha^{-1}.

For the analysis of the data, they were performed a one-way analysis of variance (Anova) and the Tukey mean test, with a significance of $p \leq 0.05$ to see if there were significant differences among the treatments, prior to this the normality test was performed, for the calculations and statistical tests the statistical program R Commander was used.

Results and discussion

Insect infestation in the corn plant

According to the analysis of variance on the number of infested plants, it indicates that there are significant differences among the treatments ($p \leq 0.05$) and the comparison of means indicates that, when applying the extract of *R. comnunis, A. mexicana* and the two entomopathogenic fungi alternated with soap, the percentage of plants infested with *M. nigripes* decreased in relation to the control treatment, where there was a greater infestation (Table 2).

Table 2. Percentages of infested plants and infestation of *M. nigripes* in the corn crop for each treatment.

Treatments alternated with soap	Infested plants (%) ± standard error	Decrease in infestation (%)
R. communis	16.5 ±0.57 a*	56
A. mexicana	20.9 ±0.4 a b	44.3
B. bassiana	20.9 ±0.5 a b	44.3
M. anisopliae	24 ±0.21 a b	36
Collection with beating net	28.4 ±0.27 b c	24.2
Control (water)	37.5 ±0.69 c	-

*= means with the same letter are not significantly different.

These results agree with the work carried out by Pérez-Torres (2012), who indicates that the application of the aqueous extract of castor oil plant (*R. communis*) alternated with bar soap (zote) at the same concentration as that used in this work reduces the infestation rate by 6.9%, protecting the crop from insects that feed on the foliage of amaranth [*Epicauta cinerea* Förster, *Herpetogramma bipunctalis* (Fabricius), *Macrosiphum* spp. L, *Pholisora catullus* (Fabricius), *S. purpurascens* and *S. exigua*] in the municipality of Atzitzihuacán.

In the same way, Aragón *et al*. (2014) confirm that treating the roselle crop with plant extracts alternated with soap is efficient, as it significantly reduces pest insect infestations compared to the control, being a good alternative for producers in Chiautla de Tapia, Puebla.

On this, Pérez-Torres *et al*. (2014) comment that, although castor oil plant extract is applied alone (without the application of soap), pest insect infestations of the foliage in the amaranth crop decrease by 27.2% with respect to the control, protecting the crop from insect damage. Ramírez (2018) expresses that this way of acting is due to the fact that this plant has a greater insecticidal activity against nematodes associated with Gardenia (Ellis).

The presence of toxic compounds such as alkaloids, phenols, ricin, ricinine and terpenoids in the seeds of this plant (Oliveira *et al*., 2002; Upasani *et al*., 2003; Demant *et al*., 2012) have the ability to cause three different types of reactions in insects: a) insecticidal effect that causes insect mortality (Rodríguez-Palma *et al*., 2017); b) feeding inhibitor (Abdalla *et al*., 2009); and c) insectistatic effect that inhibits normal insect development (Ramos-López *et al*., 2010). These characteristics could cause the treatment of *R. communis* to present the lowest infestation of *M. nigripes* in corn plants.

With respect to the treatment of *A. mexicana*, it caused a significant difference of 20.9%, the same as the treatment where *B. bassiana* was applied. These data agree with Rojas (2021), who points out that the Mexican prickly poppy extract, at the same concentration alternated with zote soap, reduces the number of insects in corn plants throughout their phenology, unlike the control treatment where only water is applied, while research carried out by Pérez-Torres (2012) confirm that, when a technological package based on plant extracts and zote soap is carried out in different crops, there is a decrease in the number of pest insect infestation, presenting a better development and protection of the crop.

The toxicity exerted by *A. mexicana* on insects is due to the presence of isoquinoline alkaloids such as: protopine, berberine and sanguinarine, which cause lethargy and death of the insect within a few hours of being ingested (Castillo and Lino, 2003). The presence of dihydrosanguinarine, coptisine, allocryptopine and dihydrocelerine is also reported, which, in addition to being toxic, acts as a repellent against various insects (ant, pear blight beetle, Mexican bean beetle, corn weevil, corn moth, cotton and sugarcane pests) including *S. frugiperda* larvae (Sharma *et al*., 2010).

As also confirmed by Salvadores *et al*. (2007), commenting that the extract of *A. mexicana* has anti-feeding and toxic properties on *Sitophilus zeamais* Motschulsky (Coleoptera: Curculionidae). Although all parts of the plant are considered toxic, the concentration of these alkaloids varies according to the parts of the plant used, most of which are concentrated in the seeds (Puig, 2005; Vázquez-Flota *et al*., 2018), in this work, the aerial part of the plant was used for the preparation of the extract, which could cause that it did not present a similar or better effect than that of *R. communis* in the reduction of infestation of *M. nigripes*.

There are few studies that report the susceptibility of coleopterans in adult stage to the application of *B. bassiana* and *M. anisopliae,* in this work it was observed that *M. anisopliae* presented a decrease in the percentage of infestation of 36%, while *B. bassiana* of 44.3%, where it had better effect with the application of the latter, these results corroborate that not only the larval stages are affected by the application of these fungi, but also adults, as reported by Almeida *et al*. (2005) for the species *Anthonomus grandis* Boheman.

Aragón *et al*. (2021) performed laboratory-level tests of *B. bassiana* for the control of *S. zeamais* at a concentration of 1.1^9, finding that the number of individuals was not as effective as when performing a combination of *B. bassiana* + lime, where decreasing the number of individuals and damages decreased by 3.3% at 81 days.

Corn production

The result of the production means for each treatment presented in Table 3 show that the highest production of corn was obtained in the plants that were treated with the extract of *R. communis* alternated with soap extract, as they presented the highest average production of 9.1 t ha^{-1}, obtaining an increase in production of 36%. Followed by *A. mexicana* and the entomopathogenic fungus (*M. anisopliae*) with 8.7 and 8.4 t ha^{-1}, representing an increase of 30 and 25.3% respectively, while the lowest production was obtained in the plants that were subjected to the control treatment with an average of 6.7 t ha^{-1}.

Table 3. Percentage and increase in corn production under different treatments.

Treatments alternated with soap	Production (t ha^{-1} ± standard error)	Increase in production with respect to the control (%)
R. communis	9.1 ±0.24 a*	36
A. mexicana	8.7 ±0.2 ab	30
M. anisopliae	8.4 ±0.62 ab	25.3
B. bassiana	8.2 ±0.29 ab	22.3
Collection with beating net	8 ±0.08 bc	19.4
Control	6.7 ±0.07 c	-

*= means with the same letter are not significantly different.

These results are similar to those reported by Pérez-Torres *et al*. (2009), who reported that the production of the control is exceeded by the treatments to which this type of bioinsecticides, alternated with bar soap, is applied, because they protect the crop from insects that damage the foliage of the plants; likewise, Pérez-Torres *et al*. (2011) indicate that the use of aqueous extract of *R. communis* and the application of soap is more effective in repelling and protecting the amaranth crop against foliage insects, presenting a production of 1 105.3 kg ha^{-1}, increasing its production up to 61%.

These results are similar to those obtained by Perales *et al*. (2015), when evaluating the effect of castor oil plant extract on whitefly, they found that the leaf extract of this plant applied in bioactive form reduces infestation by 49% and increases five times the yield of tomato (*Solanum lycopersicum*). While De la Torre (2017) indicates that the production of amaranth seed was favored with the effect of a mixture of two plant extracts, *R. communis* and *Capsicum frutensis*, reducing pests and protecting the crop.

The effectiveness of *A. mexicana* contrasts with what was indicated by Rojas (2021), who tested two ways of making extract of Mexican prickly poppy (aqueous and oily), presenting the highest production of corn with the oil-based extract followed by the aqueous extract with 12 371.5 and 11 107.2 kg ha^{-1}, in addition to performing the applications alternated with bar soap. Aragón and Tapia (2009) argue that, with the applications of *R. communis* and *A. mexicana* in amaranth plants, there is better protection in the amaranth crop from damage by pest insects in the foliage and therefore a higher seed production is obtained, with 1 951 and 1 251 kg ha^{-1}.

Relating the infestation with the production, it is observed that there is an inverse relationship, since the greater the infestation the lower the production and this is probably due to the fact that both plant extracts and entomopathogenic fungi protect corn plants from the damage caused by *M. nigripes*; in the same way, Upasani *et al*. (2003) comment that the seed of *R. communis* has insecticidal activity against some coleopterans, confirming the insecticidal activity of this plant on this insect in this work.

In addition, the effect of soap on insects is the decomposition, destruction or disruption of the permeability of the cuticle and cell membrane, this makes it more vulnerable to external factors such as heat and pathogens, causing desiccation and their death (Vincent *et al*., 2003). In immature and imago insects with soft body, soap acts by contact, dissolves the body's cuticle to be exposed to the sun or climatic changes and it tends to dehydrate and dies, hence the application of soap alternated with the plant extract favors mortality, therefore, infestation and therefore an increase in production.

Conclusions

The application of plant extracts of *R. communis* and *A. mexicana* alternated with the application of soap is a viable alternative for the management of *M. nigripes* which causes damage to the corn crop in the municipality of Huejotzingo, Puebla, Mexico, since they are made from wild plants that are within the study area, it is a renewable resource, they are biodegradable, having the particularity of decomposing quickly after being applied, there is a low decrease in residual risk in food and they cause minimal impact on enemies.

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