**Revista de Ciencias Agrícolas**
e-ISSN 2256-2273
https://doi.org/10.22267/rcia.20244101.229

Research article: Food and agricultural biotechnology.

# Control failure of deltamethrin in Colombian populations of *Rhyzopertha dominica* (F.) (Coleoptera: Bostrichidae)

## Falla de control de deltametrina en poblaciones colombianas de *Rhyzopertha dominica* (F.) (Coleoptera: Bostrichidae)

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**Cite:** Ramírez-Cabrera, C.; López-Díaz, G.; Canal, N. A.; Bacca, T. (2024). Control failure of Deltamethrin in Colombian populations of *Rhyzopertha dominica* (F.) (Coleoptera: Bostrichidae). *Revista de Ciencias Agrícolas*. 41(01): e1229. http://doi.org/10.22267/rcia.244101.229

Received: February 02 2024. Accepted: April 10 2024.

## ABSTRACT

*Rhyzopertha dominica* (F.) is a major pest in stored cereals in Colombia, which causes significant losses in production. Chemical control is the main tool used in the country, and despite the common use of insecticides such as deltamethrin, resistance has been observed in some Colombian populations but is a worldwide problem. The objective of this work was to evaluate the efficacy of deltamethrin and the combination of deltamethrin and piperonyl butoxide in Colombian populations of *R. dominica*. Failure to control and survival tests showed that the recommended doses on product labels were insufficient to protect the grain from this pest. Failure control demonstrated that mortality did not exceed 80 percent in the populations studied. Differences in susceptibility were observed between populations, with El Espinal and Neiva highlighted as less susceptible and Pore as the most sensitive to the action of insecticides. The combination of deltamethrin and piperonyl butoxide reduced insect survival but did not effectively control it (0–20%). These results suggest that *R. dominica* may be developing resistance to insecticides, as has been found in other countries. This underscores the importance of conducting toxicological studies and the need to investigate molecules with diverse modes of action, contributing to the strengthening of chemical management strategies. To achieve effective control, it is necessary to implement Integrated Pest Management (IPM) with a focus on alternative methods to chemical control.

**Keywords:** Lesser grain borer; pyrethroid; stored products; rice.

## RESUMEN

*Rhyzopertha dominica* (F.) es una plaga importante en los cereales almacenados en Colombia, que causa pérdidas significativas en la producción. El control químico es la principal herramienta utilizada en el país, a pesar del uso común de insecticidas, como la deltametrina, se ha observado resistencia en algunas poblaciones colombianas, pero es un problema mundial. El objetivo de este trabajo fue evaluar la eficacia de la deltametrina y la combinación de deltametrina más butóxido de piperonilo en poblaciones colombianas de *R. dominica*. Pruebas de falla de control y supervivencia, revelaron que las dosis recomendadas en las etiquetas de los productos eran insuficientes para proteger el grano de esta plaga. La falla de control mostró a que la mortalidad no superó el 80 por ciento en las poblaciones estudiadas. Se observaron diferencias de susceptibilidad entre poblaciones, destacando El Espinal y Neiva como las menos susceptibles y Pore como la más sensible a la acción de los insecticidas. La combinación de deltametrina y butóxido de piperonilo redujo la supervivencia del insecto, pero no lo controló eficazmente (0-20%). Estos resultados sugieren que *R. dominica* puede estar desarrollando resistencia a los insecticidas, como se ha constatado en otros países. Esto subraya la importancia de realizar estudios toxicológicos y la necesidad de investigar moléculas con diversos modos de acción, contribuyendo al fortalecimiento de las estrategias de manejo químico. Para lograr un control eficaz, es necesario aplicar el manejo integrado de plagas enfocándose en métodos de control alternativos al químico.

**Palabras clave:** Barrenador menor de los granos; piretroide; productos almacenados; arroz.

## INTRODUCTION

Production of cereals plays a crucial role in the global food supply, representing between 15% and 20% of protein intake in either humans or animals (Safdar *et al*., 2023). In Colombia, more than 2 million tons were produced in 2021; however, 9 million tons were imported, according to the National Federation of Cereal, Legume, and Soybean Growers (Fenalce, 2023). Due to their seasonal nature and permanent consumption, storage is a requirement (Richards *et al*., 2002).

In this context, the lesser grain borer, *Rhyzopertha dominica* (F.), stands out as a primary pest (García-Lara *et al*., 2007). This insect, belonging to the Bostrichidae family, is 2 to 3 mm long and 0.8 to 1 mm wide, with a color ranging from reddish brown to dark brown (Fisher, 2013). Its thorax shows a crenulated dome-shaped anterior margin, and the thorax and elytra have distinctive dimples. The antenna is short, with ten segments and a loose, three-jointed terminal club (Fisher, 2013; Majeed *et al*., 2015).

It is a polyphagous and cosmopolitan insect (Edde, 2012), noted for its robust mandibles in both larvae and adults, which are adapted to feed on the germ and endosperm of grains (Fisher, 2013), exhibiting a high fecundity rate and a wide range of temperature and humidity (Chanbang *et al*., 2008). It produces adverse changes in the composition of grains, such as loss of weight, germination capacity, nutritional value, and malodor, resulting in significant damage to cereals such as wheat, corn, and rice (Chanbang *et al*., 2008; Perišić *et al*., 2021), with losses ranging from 10% to 23% of the total cereal production stored in Colombia (Malagon & Trochez, 1985).

There are different control measures based on Integrated Pest Management (IPM) (Abrol, 2013), such as cultural control, physical control, biological control, and chemical control based on the application of pesticides; however, the latter is usually the most effective method and has specific measures for its use (Carvalho, 2017). In Colombia, chemical control is the main method for controlling *R. dominica,* and only two classes of molecules are authorized: organophosphates (pirimiphos-methyl) and pyrethroids (deltamethrin and bifenthrin), and also the fumigant phosphine, according to the Colombian Agricultural Institute (ICA, 2022).

Resistance of *R. dominica* to phosphine has been reported (Collins *et al*., 2002; Edde, 2012; Yang *et al*., 2018). Active ingredients, like pyrethroids used in stored grain pest control, have exhibited control failures and resistance in evaluations conducted in eastern Australia and two populations in Colombia (Daglish & Nayak, 2018; Salcedo-Ortega *et al*., 2021). In addition, there is evidence of genetic resistance to pyrethroids in other stored grain pests, such as *Sitophilus* spp. Haddi *et al*. (2018) found mutations in the site of action of pyrethroids (knockdown resistance [kdr]) in Brazilian populations. The objective of the present research was to evaluate the efficacy of two insecticides, deltamethrin and deltamethrin, combined with piperonyl butoxide (Delmetrin and K-Obiol) in the control of *R. dominica* in six populations from Colombia. The purpose is to establish scientific bases to guide the management and prevention of *R. dominica* resistance to chemical insecticides and contribute to the rational and efficient use of pesticides in the storage of cereals in Colombia.

## MATERIAL AND METHODS

**Rearing of *Rhyzopertha dominica*.** Populations of *R. dominica* were collected from mills in: Puerto Lopez (4°5’56.8’’ N 72°57.388’’ W) and Granada (3°32’46.5’’ N 73°42.412’’ W) from the department of Meta, El Espinal (4°08’55’’ N 75°52’55’’ W), Neiva (2°55’38.3’’ N 75°16.913’ W), Pore (5°43’40.5’’ N 71°59.56’ W), and Córdoba (8°22′00″N 75°42′00″W) from the departments of Tolima, Huila, Casanare, and Córdoba, respectively. Insects were reared and tested under laboratory conditions in the Entomology Laboratory of the University of Tolima in the department of Tolima, Colombia. The rearing process, conducted under controlled laboratory conditions (temperature: 27 ± 2°C, relative humidity: 64.8 ± 5%, photoperiod: 12:12), adhered to specific parameters.

Insects were reared on broken rice in 4-liter plastic containers covered with pieces of organza veil secured with an elastic band, which was changed every two months to avoid contamination by fungi or other organisms. To prevent any previous insect infestation, the rice grains used for rearing and experiments were initially classified by removing damaged grains and sterilized by incubation for 72h at a temperature of -18°C. Two days before use, we brought the rice grains to laboratory temperature (Salcedo-Ortega *et al*., 2021). The moisture content of the grains was approximately 11.5%.

**Control failure assessment.** The control failure consisted of exposing unsexed adults of *R. dominica* from the six populations collected to the doses indicated on the label of commercial products containing the pyrethroid deltamethrin. The commercial products used were Deltametrin® 2.50EC (C.I. Entquim Ltda, Bogotá D.C., Colombia, 60 ml/1000 kg of grain) and K-Obiol® EC25 (Bayer Crop Science, Bayer S.A., Bogotá, DC, 20 ml/1000 kg of grain). According to the Colombian Institute of Agriculture (ICA), the 80% mortality threshold was employed as the basis for control failure assessments.

We soaked 300 g of paddy rice with the indicated dose of the insecticide in 9 ml of water and 0.5% Agrotin® SL adjuvant (Bayer Crop Science, Bayer S. A., Bogotá, DC, Colombia). After shaking the rice for three minutes to ensure the impregnation of all grains, it was air-dried for one hour and then separated into groups of 30 g in 250-ml glass bottles. The control involved paddy rice impregnated with water and Agrotin 0.5%. Each treatment consisted of ten replicates. We evaluated mortality rates (considering organisms without any movement after 5 minutes of observation as dead) at 24, 48, 72, and 144 hours after exposing *R. dominica* to each treatment.

**Residual effects and survival bioassay**. In this trial, we applied the commercial doses to rice, as previously mentioned. We assessed adult survival until reaching a 90% mortality rate. We maintained consistency with the protocol detailed above for the bioassay. The control group received a treatment composed exclusively of water and 0.5% Agrotin. We recorded mortality daily for 35 days. A total of 100 adult insects were used for each combination of population and insecticide concentration.

**Data Analysis**. A two-way analysis of variance (ANOVA) was performed for the control failure tests, with insecticides as independent variables, followed by a Tukey mean comparison test. The results of the survival bioassays were subjected to survival analysis, which was performed using Kaplan-Meier estimators (Log-rank method). Insects that remained alive at the end of the bioassay were censored for analysis. The overall similarity between survival times and median survival ($LT_{50}$ values) was tested using the log-rank test $\chi^2$, and pairwise comparisons between curves were performed using the Holm-Sidak test ($P < 0.05$).

 

## RESULTS AND DISCUSSION

**Control failure assessment.** The cumulative mortalities of the two insecticides evaluated did not reach 80% during 144-h, with 48-h mortality rates ranging from 2% to 12% (Table 1).

In El Espinal, a cumulative mortality of 17% at 48-h was observed with the application of deltamethrin + piperonyl butoxide (Table 1), as had been reported previously for a population from the same place by Salcedo-Ortega *et al*. (2021). Similarly, in the Neiva population, a mortality rate of 21% was recorded, indicating a behavior comparable to that observed in El Espinal. This similarity could be attributed to El Espinal and Neiva showing similar agricultural conditions and being located near comparable ecological environments.

Significant differences in insecticide effectiveness were only evident after 144-h in the populations of Cordoba, Granada, and Pore ($F= 48.48$, $df= 2$, $P < 0.0001$) (Table 1). In this context, the combination of deltamethrin and piperonyl butoxide showed greater efficacy, achieving mortality rates of 44%, 36%, and 48%, respectively, compared to the exclusive use of deltamethrin (Table 1). Piperonyl butoxide exhibits a synergistic effect, which acts as an inhibitor of the metabolic detoxification of insects (Shakya *et al*., 2022). It binds non-covalently to the cytochrome P450 enzyme (Hodgson & Levi, 1999), altering the function of the oxidases responsible for detoxification and affecting their ability to metabolize molecules such as pyrethroids (Fouad *et al*, 2023). Frequently, a reduction in susceptibility to deltamethrin, attributed to the effect of piperonyl butoxide on stored grain pests, has been observed ( Arthur, 1994; Arthur *et al*., 2020; Fouad *et al*., 2023; Salcedo-Ortega *et al*., 2021).

**Table 1.** Cumulative mortality (%) of *Rhyzopertha dominica*, means with a common letter are not significantly different (p > 0.05).

| Insecticide | Population | Cumulative mortality (% ± SE) after exposure | | | |
|---|---|---|---|---|---|
| | | 24h | 48h | 72h | 144h |
| Deltamethrin | Cordoba | 2.00 (± 1.35) a | 4.00 (±2.08) ab | 5.00 (± 2.35) a | 14.00 (± 3.60) abc |
| | Granada | 0.00 (± 1.35) a | 0.00 (± 2.08) a | 0.00 (± 2.35) a | 2.00 (± 3.60) a |
| | El Espinal | 0.00 (± 1.35) a | 2.00 (± 2.08) ab | 2.00 (± 2.35) a | 5.00 (± 3.60) ab |
| | Neiva | 3.00 (± 1.35) a | 6.00 (±2.08) ab | 9.00 (± 2.35) ab | 21.00 (± 3.60) bcd |
| | Pore | 0.00 (± 1.35) a | 1.00 (± 2.08) a | 6.00 (± 2.35) a | 28.00 (± 3.60) cde |
| | Puerto Lopez | 5.00 (± 1.35) a | 5.00 (± 2.08) ab | 9.00 (± 2.35) ab | 49.00 (± 3.60) f |
| Deltamethrin + piperonyl butoxide | Cordoba | 5.45 (± 1.29) a | 8.00 (± 2.08) ab | 11.00 (± 2.35) ab | 44.00 (± 3.60)ef |
| | Granada | 1.00 (± 1.35) a | 3.00 (± 2.08) ab | 6.00 (± 2.35) a | 36.00 (± 3.60) def |
| | El Espinal | 0.00 (± 1.35) a | 2.00 (± 2.08) ab | 2.00 (± 2.35) a | 17.00 (± 3.60) abc |
| | Neiva | 3.00 (± 1.35) a | 5.00 (± 2.08) ab | 7.00 (± 2.35) a | 21.00 (± 3.60) bcd |
| | Pore | 1.00 (± 1.35) a | 4.00 (± 2.08) ab | 6.00 (± 2.35) a | 48.00 (± 3.60) f |
| | Puerto Lopez | 5.00 (± 1.35) a | 12.00 (± 2.08) b | 20.00 (± 2.35)b | 41.00 (± 3.60) ef |

Our results corroborate the presence of control failure in all evaluated populations at the recommended label doses of both insecticides studied and the low level of protection of grains from *R. dominica* in Colombia. These results are in agreement with preliminary findings in the Tolima department in Colombia by Salcedo-Ortega *et al*. (2021) and in other research worldwide too (Daglish & Nayak, 2018; Kavallieratos *et al*., 2015; Lorini & Galley, 1998; Salcedo-Ortega *et al*., 2021; Trostanetsky *et al*., 2023).

This resistance has been frequently attributed to the use of insecticides at high doses (Barathi *et al*., 2024; Helps *et al*., 2020). In addition, this resistance can be caused by the limited rotation of the modes of action of the insecticides (Madgwick & Kanitz, 2024; Sparks *et al*., 2021). This is compounded by the low level of authorized chemical molecules in Colombia. The lack of variety in treatments contributes to increased selection pressure (Thia *et al*., 2023), resulting in high levels of pyrethroid resistance, as reported by Daglish & Nayak (2018) in eastern Australia. This phenomenon has been noted in other stored grain pests (Attia *et al*., 2020; Haddi *et al*., 2018). However, the populations studied came from places with high use of insecticides in agricultural ecosystems, which may increase the pressure on the insects in the field.

In this context, evaluating new molecules as an alternative to pyrethroids and organophosphates is essential. Although the efficacy of organophosphates, specifically pirimiphos methyl (Actellic®), has been proven to control *R*. *dominica* (Salcedo-Ortega *et al*., 2021), it is essential to explore other molecules to strengthen and diversify management strategies. The concern lies in the current existence of only one effective molecule on the market for the management of *R*. *dominica* in stored grains, which highlights the need for further studies on the efficacy of other molecules with different modes of action to be included in pest management and control plans.

**Residual effects and survival bioassay.** The results of the survival bioassays revealed significant differences in the mean survival time of *R. dominica* adults treated only with deltamethrin. The least susceptible population found was El Espinal, with an $LT_{50}$ of 29.620 (27.681-31.559) days, while the most susceptible populations, such as Pore and Puerto Lopez, exhibited mortality within days; others were positioned at intermediate levels (log-rank test, $X^2 = 277.753$, df = 5, $P < 0.001$) (Figure 1). It is important to note that the El Espinal population in our assays showed a lower $LT_{50}$ compared to the study by Salcedo-Ortega *et al*. (2021).

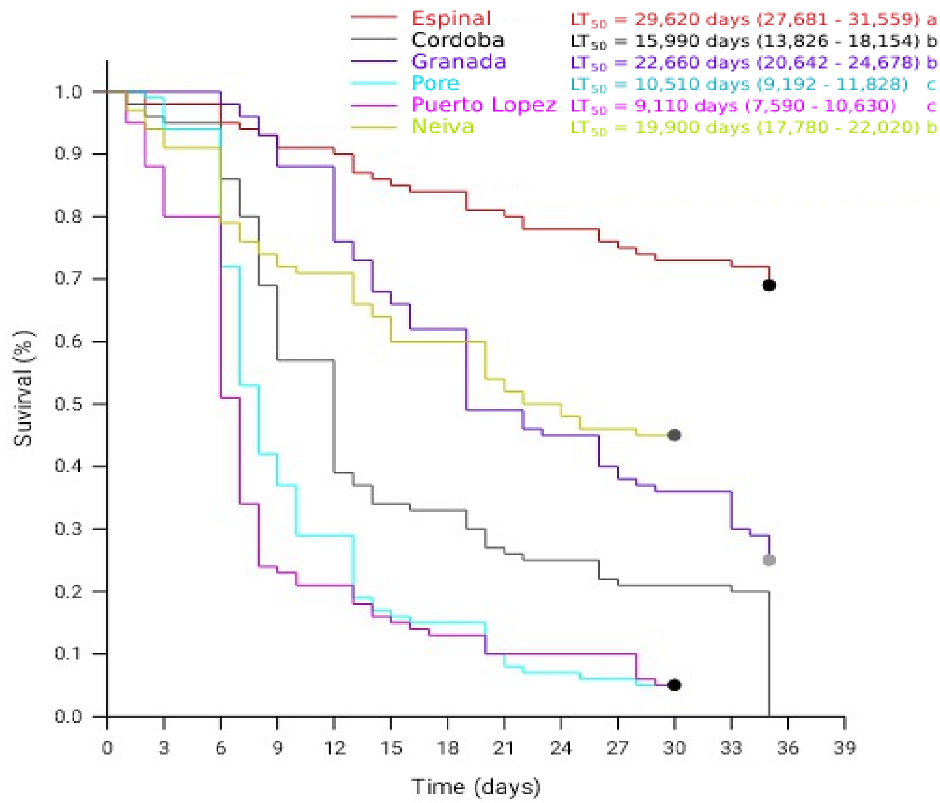


**Figure 1.** Survival curves of six Colombian populations of *Rhyzopertha dominica* exposed to commercial pyrethroids: Deltamethrin**.** The curves labeled with the same letter are not significantly different according to a Holme-Sidak test ($P > 0.05$).

Significant differences were observed in the treatment with deltamethrin + piperonyl butoxide, leading to the identification of three distinct groups (Log-rank test, $X^2 = 133.866$, df = 5, $P < 0.001$). The least susceptible group consisted of El Espinal and Neiva, followed by Córdoba, Granada, and Puerto López (Figure 2). Pore was identified as the most susceptible population, exhibiting an $LT_{50}$ of 7.060 (6,478-7,642) days.

These results show different residual effects on populations between the two insecticides. El Espinal and Neiva stand out as the least susceptible populations to the insecticides evaluated. On the opposite side, Pore stands out as the most susceptible population with the lowest mean lethal time. El Espinal and Neiva are located in areas with a long history of intensive insecticide use in commercial agriculture, particularly in crops such as rice, corn, and cotton. In contrast, the region where Pore is situated has relatively recently adopted these agricultural practices. Our findings indicate a correlation between the duration of exposure to insecticides in agricultural settings and the observed susceptibility levels of *R. dominica* populations.

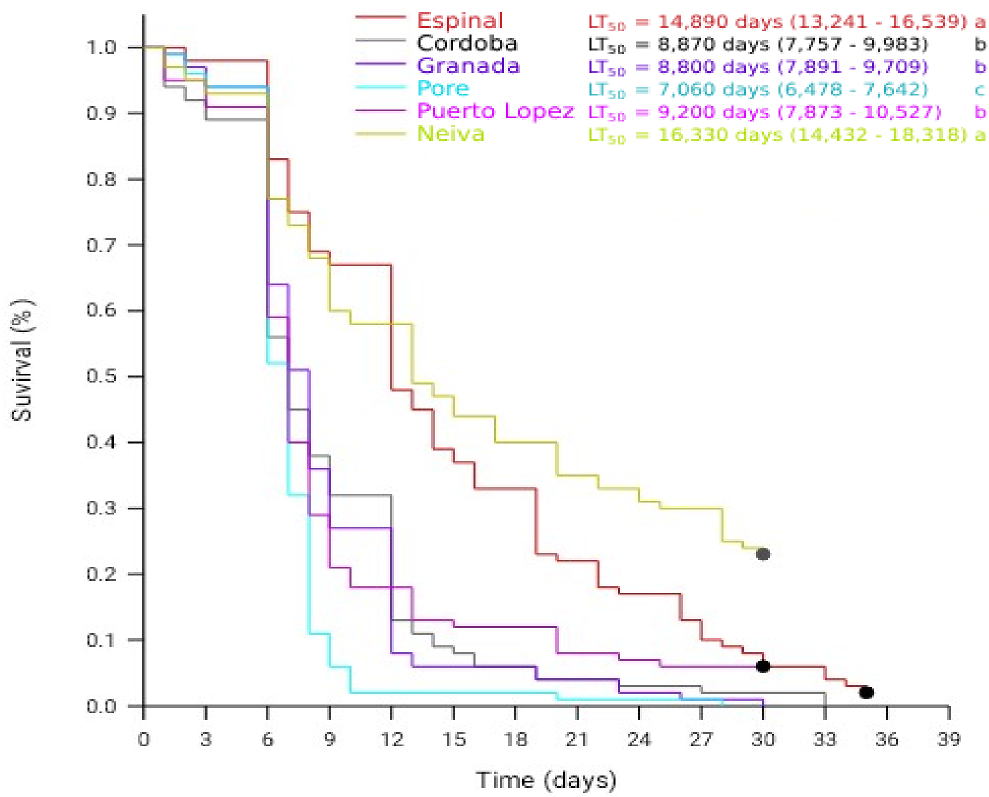


**Figure 2.** Survival curves of six Colombian populations of *Rhyzopertha dominica* exposed to commercial pyrethroids: Deltamethrin + piperonyl butoxide. The curves labeled with the same letter are not significantly different according to a HolmeSidak test (P > 0.05).

In addition, we observed that insect survival in all populations was significantly lower when treated with deltamethrin + piperonyl butoxide compared to the treatment with deltamethrin alone (Figure 2 vs. Figure 1). However, despite this reduction in survival, this treatment does not achieve effective control of *R. dominica*.

## CONCLUSIONS

The possible resistance of *R. dominica* to insecticides is noted, highlighting the need for toxicological studies to determine its degree of resistance. In addition, it is important to research the efficacy of molecules with different modes of action to strengthen chemical management strategies. Likewise, the implementation of Integrated Pest Management (IPM) is essential, emphasizing alternative methods such as cultural, physical, and biological control. These findings highlight the urgency of addressing resistance and diversifying approaches for effective control of this pest.

## ACKNOWLEDGMENTS

This research was financed by Universidad del Tolima (Oficina de Investigaciones y Desarrollo Científico – Department of Scientific Research and Development). We would also like to acknowledge the support from 'Fitogranos Comercializadora Agroindustrial Limitada'. The scholarships to CRC and GLD were granted by the Ministry of Science, Technology, and Innovation of Colombia (Minciencias) through the Young Researchers Program. Also, we thank the administration and staff of the Northern Regional University Center (CURDN) of Universidad del Tolima for the logistic support through this study.

**Conflict of interest**: The authors declare that there is no conflict of interest.

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