Capsaicin in the control of *Spodoptera frugiperda* in corn (*Zea mays* L.) var. Blanco Urubamba

Capsaicina en el control de *Spodoptera frugiperda* en maíz (*Zea mays* L.) var. Blanco Urubamba

Capsaicina no controle de *Spodoptera frugiperda* em milho (*Zea mays* L.) var. Blanco Urubamba

Hecar Herrera Marchino[1]
Agustina Valverde-Rodríguez[1]*
Manuel Jorge Castillo Nole[2]
Laura Carmen Barrionuevo Torres[2]
Luisa Madolyn Alvarez-Benaute[4]
Miltao Edelio Campos-Albornoz[2]

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[1]Facultad de Ciencias Agrarias, Universidad Nacional Hermilio Valdizan, Huánuco, Perú.
[2]Facultad de Ciencias Agrarias, Universidad Nacional Daniel Alcides Carrión, Cerro de Pasco, Perú.
[3]Facultad de Ciencias de la Educación, Carrera Profesional de Biología y química, Universidad Nacional Hermilio Valdizan, Huánuco, Perú.
[4]Facultad de Ciencias Agrarias, Universidad Nacional Hermilio Valdizan, Huánuco, Perú.

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Abstract

Spodoptera frugiperda Smith (Lepidoptera: Noctuidae) causes severe losses in corn (*Zea mays* L.) crops, which leads to the evaluation of sustainable management alternatives. The objective of this research was to determine the efficacy of capsaicin in controlling *S. frugiperda* in the corn Blanco Urubamba var. A randomized complete block design with six treatments and three replicates was used: four concentrations of water-soluble capsaicin (6.70; 10.05; 13.40 and 16.75 $mL.L^{-1}$), rocoto pepper extract (*Capsicum pubescens* Ruiz & Pav. (Solanaceae), 50 $g.L^{-1}$), and an absolute control. Applications were made at 80, 90, 100, 110, and 120 days after sowing (das). The 16.75 $mL.L^{-1}$ dose was the most effective, reducing larval density from 3.12 to 0.13 larvae per plant, and the infestation percentage from 61.12 to 2.78 %, with a control efficacy of 96.69 %. Intermediate concentrations (13.40 and 10.05 $mL.L^{-1}$) also showed significant effects, with final efficacies of 93.83 and 85.19 %, respectively. T1 had moderate efficacy (78.30 %), while T5 recorded the lowest control values (72.86 %), with increasing infestations being observed in the control. In terms of yield, T4 (16.75 $mL.L^{-1}$) produced ears of 16.77 cm in length and 385.13 g in average weight, reaching a yield of 17.12 $t.ha^{-1}$ compared to 9.54 $t.ha^{-1}$ for the control. In conclusion, water-soluble capsaicin, especially at 16.75 $mL.L^{-1}$, proved to be an effective and sustainable alternative for the management of *S. frugiperda* in corn.

*Corresponding author: avalverde@unheval.edu.pe

Resumen

Spodoptera frugiperda Smith (Lepidoptera: Noctuidae) ocasiona severas pérdidas en el cultivo de maíz (*Zea mays* L.), esto conlleva a evaluar alternativas sostenibles de manejo. El objetivo de la investigación fue determinar la eficacia de la capsaicina en el control de *S. frugiperda* en maíz var. Blanco Urubamba. Se utilizó un diseño de bloques completamente al azar con seis tratamientos y tres repeticiones: cuatro concentraciones de capsaicina hidrosoluble (6,70; 10,05; 13,40 y 16,75 mL.L^{-1}), extracto de rocoto (*Capsicum pubescens* Ruiz & Pav. (Solanaceae), 50 g.L^{-1}) y un testigo absoluto. Las aplicaciones se realizaron a los 80, 90, 100, 110 y 120 días después de la siembra (dds). La dosis de 16,75 mL.L^{-1} fue la más efectiva, reduciendo la densidad larvaria de 3,12 a 0,13 larvas por planta, el porcentaje de infestación de 61,12 a 2,78 % con una eficacia de control de 96,69 %. Las concentraciones intermedias (13,40 y 10,05 mL.L^{-1}) también mostraron efectos significativos, con eficacias finales de 93,83 y 85,19 %, respectivamente. T1 tuvo eficacia moderada (78,30 %), mientras que T5 registró los menores valores de control (72,86 %), observándose infestaciones crecientes en el testigo. En rendimiento, T4 (16,75 mL.L^{-1}) produjo mazorcas de 16,77 cm de longitud y 385,13 g de peso promedio, alcanzando un rendimiento de 17,12 t.ha^{-1} frente a 9,54 t.ha^{-1} del testigo. En conclusión, la capsaicina hidrosoluble, especialmente a 16,75 mL.L^{-1}, demostró ser una alternativa eficaz y sostenible para el manejo de *S. frugiperda* en maíz.

Palabras clave: ajíes, eficacia, bioinsecticidas, infestación, rendimiento

Resumo

Spodoptera frugiperda Smith (Lepidoptera: Noctuidae) causa perdas severas em culturas de milho (*Zea mays* L.), o que leva à avaliação de alternativas de manejo sustentável. O objetivo desta pesquisa foi determinar a eficácia da capsaicina no controle de *S. frugiperda* em milho Blanco Urubamba var. Utilizou-se o delineamento em blocos casualizados com seis tratamentos e três repetições: quatro concentrações de capsaicina solúvel em água (6,70; 10,05; 13,40 e 16,75 mL.L^{-1}), extrato de rocoto (*Capsicum pubescens* Ruiz & Pav. (Solanaceae), 50 g.L^{-1}) e uma testemunha absoluta. As aplicações foram feitas aos 80, 90, 100, 110 e 120 dias após o plantio (das). A dose de 16,75 mL.L^{-1} foi a mais efetiva, reduzindo a densidade larval de 3,12 para 0,13 larvas por planta, o percentual de infestação de 61,12 para 2,78 %, com eficácia de controle de 96,69 %. Concentrações intermediárias (13,40 e 10,05 mL.L^{-1}) também apresentaram efeitos significativos, com eficácias finais de 93,83 e 85,19 %, respectivamente. T1 apresentou eficácia moderada (78,30 %), enquanto T5 registrou os menores valores de controle (72,86 %), sendo observadas infestações crescentes na testemunha. Em termos de produtividade, o T4 (16,75 mL.L^{-1}) produziu espigas com 16,77 cm de comprimento e 385,13 g de peso médio, atingindo uma produtividade de 17,12 t.ha^{-1}, contra 9,54 t.ha^{-1} da testemunha. Conclui-se que a capsaicina hidrossolúvel, especialmente na dose de 16,75 mL.L^{-1}, demonstrou ser uma alternativa eficaz e sustentável para o manejo de *S. frugiperda* na cultura do milho.

Palavras-chave: pimentas, eficácia, bioinseticidas, infestação, rendimento

Introduction

Spodoptera frugiperda Walker (Lepidoptera: Noctuidae) is a polyphagous pest that poses the greatest threat to corn crops from its early stages of growth, causing economic losses of up to 60 % in tropical and subtropical regions (Lamsal *et al*., 2020; Clark *et al*., 2007). During the larval stage, *S. frugiperda* feeds voraciously on leaves and tender shoots, affecting the vegetative development of corn (Neira and Pérez, 2020; Paredes-Sánchez *et al*., 2021; Ministry of Agricultural Development and Irrigation [MIDAGRI], 2020). Various studies indicate that the incidence and damage caused by the pest decrease after the stem elongation phase (Montezano *et al*., 2018; Du Plessis *et al*., 2020). According to Du Plessis *et al*. (2020), its adaptability to adverse geographical conditions and a wide variety of plants, including larvae of the same species, increase its devastating impact on agricultural systems (Du Plessis *et al*., 2020).

In Peru, the management of *S. frugiperda* has been hindered by the excessive and indiscriminate use of chemical insecticides (Van den Berg & Du Plessis, 2022; Miranda *et al*., 2021; Kim *et al*., 2023).

In response to these problems, sustainable alternatives based on plant-based insecticides have been explored, including compounds extracted from chili peppers (*Capsicum annuum*) (Solanaceae), in particular capsaicin (8-methyl-*N*-vanillyl-6-nonenamide), an alkaloid found in the fruit of *Capsicum* spp. (Ahn *et al*., 2011; Ahmed, 2022; Caterina *et al*., 1997; Aza-González *et al*., 2011). It has been documented that capsaicin inhibits oviposition in the onion fly *Delia antiqua Meigen* (Diptera: Anthomyiidae) (Cowles *et al*., 1989) and reduces the feeding of the ladybug *Henosepilachna vigintioctomaculata* Motschulsky (Coleoptera: Coccinellidae) (Hori *et al*., 2011). In addition, it has larvicidal activity against *Anopheles stephensi* Liston (Diptera: Culicidae) and *Culex quinquefasciatus* Say (Diptera: Culicidae) (Madhumathy *et al*., 2007), and larvae of *S. frugiperda* (Santoa and Santos, 2024).

Capsaicin acts as an irritant, which induces a repellent response in insects (Castillo-López *et al*., 2017; Ahmed, 2022), also minimizes environmental risks and does not leave toxic residues (Gonçalves *et al*., 2021; Cárdenas-De la Peña *et al*., 2022; Figueroa *et al*., 2019; Rakesh *et al*., 2024).

The objective of this study was to evaluate the efficacy of capsaicin in the control of *S. frugiperda*, determining its effectiveness in reducing larvae and exploring its potential as a sustainable solution in the phytosanitary control of this pest in corn crops.

Materials and methods

Study area

The study was carried out in the Huánuco region (8°36’25.4” south latitude; 77°09’15.7” west longitude, 3,034 m a.s.l.), Peru. Tropical lower montane dry forest (bs-MBT) (Holdridge, 1987). The climate is temperate, with temperatures between 17.5 °C and 8.0 °C, seasonal precipitation, and moderate thermal amplitude (National Service of Meteorology and Hydrology of Peru [SENAMHI], 2024).

Plant material

The plant material was corn (*Zea mays* L.) var. Blanco Urubamba, selected for its wide local adaptability and regional economic value.

Experimental design

A randomized complete block design (RCBD) was used, consisting of four blocks, six treatments, and three replications. The plots were 4.50 m x 3.60 m (16.2 m²) with four rows and 10 plants per row, planted at a distance of 0.90 m between rows and 0.30 m between plants, as well as 2 m between blocks.

The treatments consisted of four concentrations of water-soluble capsaicin (Bioxter®) at doses of 6.70, 10.05, 13.40, and 16.75 $mL.L^{-1}$; a treatment with rocoto pepper extract (*Capsicum pubescens* Ruiz & Pav., Solanaceae) at doses of 50 $g.L^{-1}$ and an absolute control (without application).

The applications were carried out with a backpack spray (Jacto PJH model, Brazil) at constant pressure, at 80, 90, 100, 110, and 120 days after sowing (das) of the corn plants. Capsaicin was applied to corn buds that had larvae in early stages (L1 to L3), visually identified by their size (3-15 mm), these being the most susceptible stages of the insect (Stirle *et al*., 2024).

Variables evaluated

Larval infestation. It was determined by counting live larvae per plant. For each evaluation, 10 plants per plot were randomly selected, which represented 40 plants per treatment, and a total of 240 plants per evaluation. Larval density. It was obtained by calculating in each plant and by plot, the proportion of infested plants with respect to the total evaluated (10 plants), and then the value of the four replicates per treatment was averaged. Infestation percentage. It was estimated by calculating the proportion of infested plants with respect to the total evaluated, according to the equation of Neira and Pérez (2020) (Eq. 1).

$$\text{Infestation (\%)} = \frac{\text{Number of infested plants}}{\text{Number of plants evaluated}} \text{ X } 100 \qquad \text{(Eq. 1)}$$

Control efficiency. It was estimated using the equation of Henderson and Tilton (1955) (Eq. 2).

$$\text{Efficacy (\%)} = \frac{[1\text{-(cdxTa)}]}{\text{cdxTa}} \text{ X } 100 \qquad \text{(Eq. 2)}$$

Where:

Cd: is the number of insects in the control after treatment, Ta: is the number of insects in the treatment before treatment, Ca: is the number of insects in the control before treatment, and Td: is the number of insects in the treatment after treatment. Crop yield. It was quantified as a function of the weight of the ears using a digital scale (Precisur, Truper base 5EA, Peru) and expressed in $t.ha^{-1}$.

Statistical analysis

The percentage data were transformed using equation 3 (Eq. 3).

$$Y' = \arcsin\left(\sqrt{\left(\frac{Y}{100}\right)}\right) \qquad \text{(Eq. 3)}$$

Where: *y*: represents the original percentage value and *Y'*: the transformed value.

This transformation stabilizes the variance and normalizes the distribution of proportional data, allowing the application of more robust parametric statistical analyses. The transformed values were subjected to an analysis of variance (ANOVA) to assess significant differences between treatments. The means were compared using Tukey's multiple range test with a significance level of $p<0.05$. The statistical analysis was carried out using the INFOSTAT software version 2023**,** which allowed estimating the values of F, coefficients of variation, and contrasts of means with precision.

Results and discussion

Larval density of *Spodoptera frugiperda*

Before the application of the treatments, an average density of *Spodoptera frugiperda* per plant was observed, figures that were statistically homogeneous in the experimental plot, classified as moderate infestation level 3 (Davis and Williams, 1992). This degree of infestation implies a significant impact on foliage and a considerable decrease in corn yield.

From the first application, it was evident that the T4 treatment reduced the density, followed by T3 and T2 (Table 1). T1 and T5 did not show statistically significant differences between them ($p>0.05$), but they did exceed T6, which maintained the highest larval density with an average of 3.63 larvae per plant during the first evaluation. This substance interferes with the sensory systems of insects, causing loss of appetite or even death, depending on the dose and frequency of application (Chabaane *et al*., 2021).

At 90 das, the T4 and T3 treatments showed efficacy, respectively, with no statistical differences between the treatments ($p\leq0.05$). The T2 treatment also showed a considerable reduction, while the T6 control again recorded the highest value. The decrease in larval density was confirmed at 100 and 120 das, a moment at which T4, T2, and T3 treatments achieved the lowest population density of *S. frugiperda*. These results demonstrate the sustained efficacy of capsaicin as an integrated pest management tool, highlighting its potential to significantly reduce the presence of *S. frugiperda* and, with it, mitigate foliar damage and improve crop yield.

The results obtained support the efficacy of capsaicin in the control of *S. frugiperda*, confirming its potential as a phytosanitary tool in the management of agricultural pests. As pointed out by Negrete and Morales (2003), this compound has the ability to directly

Table 1. Larval population density of *Spodoptera frugiperda*, average of larvae pre- and post-application of the treatments in corn *(Zea mays* L.) var. Blanco Urubamba.

Treatment	Pre-application	Average larvae per plant				
		Days after sowing (das)				
		80	90	100	110	120
T1 (capsaicin 6.70 $mL.L^{-1}$)	3.17 a	2.41 d	2.31 d	1.78 c	1.64 b	0.82 b
T2 (capsaicin 10.05 $mL.L^{-1}$)	3.12 a	2.09 c	1.97 c	1.46 b	1.19 ab	0.55 ab
T3 (capsaicin 13.40 $mL.L^{-1}$)	3.15 a	1.81 b	1.69 b	1.19 a	1.16 ab	0.23 a
T4 (capsaicin 16.75 $mL.L^{-1}$)	3.12 a	1.43 a	1.32 a	1.01 a	0.66 a	0.13 a
T5 (Rocoto pepper extract)	3.16 a	2.52 d	2.40 d	1.90 c	1.66 b	1.01 b
T6 (Absolute control)	3.13 a	3.63 e	4.13 e	4.66 d	4.43 c	3.75 c
CV (%)		3.01	4.41	4.15	17.94	19.34
Sx: ±		0.03	0.05	0.04	0.16	0.10
p-value		0.000	0.000	0.000	0.000	0.000

Means with a common letter are not different, Tukey's multiple range test ($p>0.05$).

affect the nervous system of larvae, generating neurological alterations that translate into disorientation, decreased appetite, and, consequently, a drastic reduction in their ability to feed and develop properly. These physiological alterations significantly increase the mortality rate of insects, which favors the population control of pests in a natural and sustainable way.

Capsaicin represents between 0.1 and 1 % of the weight of the fruit, a key range for its insecticidal action (Meckelmann *et al*., 2015; Li *et al*., 2019; Salgado-Aristizabal *et al*., 2024). Its concentration enhances toxic and repellent effects. In addition, it plays a natural defensive role in Capsicum plants against herbivores (Ahn *et al*., 2011). It acts on TRPV1 receptors in insects, causing irritation and death (Reyes-Escogido *et al*., 2011), and can lead to cumulative neurotoxic effects (Castillo-López *et al*., 2017).

However, other studies present partially different results. For example, Ahn *et al*. (2011) found that *Helicoverpa assulta*, a lepidoptera specialized in nightshades (Solanaceae), showed physiological tolerance to capsaicin, indicating that the insecticidal response varies by species and their level of specialization. This suggests that the high effect observed in *S. frugiperda*, a generalist species, is partly due to its lower adaptive tolerance to secondary metabolites such as capsaicin.

Additionally, these findings are consistent with the reports of Figueroa *et al.* (2019), who used extracts of *Capsicum chinense* Jacq. (Solanaceae) and observed a 70 % reduction in *S. frugiperda* infestation in corn under tropical conditions. This supports the applicability of the present study in Andean temperate climates, such as Huánuco, and expands the evidence of efficacy in various ecosystems.

On the other hand, treatments with rocoto pepper extract (T5), although less effective than commercial capsaicin formulations, showed a significant tendency to reduce infestation. This behavior can be attributed to the lower concentration and natural variability of capsaicinoids present in the artisanal extract, as noted by Rakesh *et al*. (2024), who showed that the formulation and type of Capsicum significantly influence insecticidal potency.

The larval reduction observed in this study is associated with higher crop yield, in agreement with Zelaya-Molina *et al.* (2022), who linked the use of capsaicin extracts with productive increases in tomato (*Solanum lycopersicum* L.) and cucumber (*Cucumis sativus* L.). However, factors such as photodegradation, environmental persistence, and formulation cost should be considered, as suggested by Sánchez-Alonso *et al*. (2024), who recommend ecotoxicological studies and large-scale field tests.

Despite the typical cannibalism of *S. frugiperda* in early larval stages (Chapman *et al*., 1999; Capinera, 2017), a high larval density was observed in the absolute control. Montezano *et al*. (2018) explain this phenomenon by the staggered oviposition, which generates overlapping cohorts, delaying the manifestation of cannibalism.

On the other hand, Chapman *et al.* (1999) pointed out that cannibalism in *S. frugiperda* decreases when there is abundant food and low competition between larvae. Tang *et al*. (2024) confirmed that this behavior arises under stress, food scarcity, or confinement, conditions that were absent in the present study, where plots with high leaf availability were observed, as in the control. In this regard, it has been reported that capsaicin does not promote cannibalism but acts as a repellent or inhibitor of food (Reyes-Escogido *et al.,* 2011; Hori *et al*., 2011).

Therefore, the persistence of the number of larvae in some plots during the evaluation time does not necessarily imply the absence of cannibalism, but a balance between the rate of re-infestation (new ovipositions), the initial density, the action of the bioinsecticide, and the availability of food, factors that together can explain the observed dynamics.

Larval incidence of *Spodoptera frugiperda*

The evaluations before the application of the treatments revealed that the percentage of infested plants ranged between 58.38 and 63.89 %, which, according to the scale of Davis and Williams (1992), corresponds to a moderate level of infestation. This degree of affectation represents a considerable risk to crop yield, thus justifying the implementation of control measures.

After the first application of capsaicin-based treatments (80 das), a notable decrease in the proportion of plants infested by *S. frugiperda* larvae was evidenced, especially in the T4 and T3 treatments (Table 2), which reduced the levels.

The decrease in larval infestation was accentuated from the third application (100 das), when the T4 treatment reduced the percentage of infested plants equivalent to a decrease of 68.8 %, compared to the initial record. In the fourth (110 das) and fifth (120 das) application, the decreasing trend was maintained, reaching the minimum infestation value observed in the entire trial in the last evaluation: only 2.78 % of the plants presented live larvae under T4 treatment (Table 2), while the absolute control was exceeded by %. These results confirm the cumulative efficacy of the T4 treatment as the applications progressed, evidencing its capacity to sustainably control the *S. frugiperda* population in the corn crop.

On the other hand, the effects of capsaicin can vary depending on the species of insect. Ahn *et al.* (2011) demonstrated that *Helicoverpa*

Table 2. Average number of infested plants in corn (*Zea mays* L.) var. Blanco Urubamba, pre- and post-application of the treatments.

Treatment	Infested plants (%)				
	Days after sowing (das)				
	80	90	100	110	120
T1 (capsaicin 6.70 mL.L^{-1})	50.00 bc	38.89 bc	27.78 ab	19.44 a	13.89 a
T2 (capsaicin 10.05 mL.L^{-1})	44.44 bc	33.33 abc	22.22 ab	16.67 a	8.33 a
T3 (capsaicin 13.40 mL.L^{-1})	33.33 ab	22.22 ab	16.67 ab	13.89 a	5.56 a
T4 (capsaicin 16.75 mL.L^{-1})	22.22 a	16.67 a	13.89 a	8.33 a	2.78 a
T5 (Rocoto pepper extract)	61.12 c	47.23 cd	33.34 b	22.22 a	16.67 a
T6 (Absolute control)	63.89 c	66.67 d	69.45 c	66.67 b	52.78 b
CV (%)	11.98	15.65	15.48	19.64	20.89
Sx: ±	0.17	0.20	0.21	0.24	0.28
p-value	0.000	0.000	0.000	0.000	0.000

Tukey's test ($p<0.05$). Figures with the same letters within the same column are statistically the same.

assulta Guenée (Lepidoptera: Noctuidae), a species specific to the consumption of plants in the family Solanaceae, showed significant physiological tolerance to capsaicin, in contrast to generalist insects such as *Spodoptera frugiperda* J.E. Smith (Lepidoptera: Noctuidae), *Heliothis virescens* Fabricius (Lepidoptera: Noctuidae), *Helicoverpa armigera* Hübner (Lepidoptera: Noctuidae), and *Helicoverpa zea* Boddie (Lepidoptera: Noctuidae).

In a pioneering study, *Helicoverpa assulta* in the crop of nightshades (Solanaceae) exhibited physiological tolerance to capsaicin: its growth increased with chronic exposures, while in generalist species such as *S. frugiperda, H. virescens, H. armigera,* and *H. zea*, a reduction in larval growth rate, increased mortality, and negative effects on digestive indices were observed, such as the relative consumption rate (RCR), the relative growth rate (RGR), and the insect conversion efficiency (ECI) (Ahn *et al*., 2011). This indicates that the insecticidal response of capsaicin is not uniform, varying according to the metabolic and adaptive capacity of each species. Research by Zhu *et al*. (2020) has related these differences to the enzymatic activity of detoxification. *Helicoverpa assulta* Guenée (Lepidoptera: Noctuidae) showed a greater ability to metabolize capsaicin and dihydrocapsaicin in tissues such as the midgut and fat body, while in *H. armigera* these metabolic pathways were less active. This supports the hypothesis that specialist insects develop adaptive mechanisms to tolerate specific compounds from their host plants.

Likewise, recent studies with generalist insects (*S. latifascia*) fed diets with different levels of capsaicin synthesis reported clear adverse effects (Chabaane *et al.,* 2021). This reaffirms that, in generalist species, capsaicin is a phytosanitary agent with high efficacy.

Efficacy of control of *Spodoptera frugiperda* larvae

The control efficacy of each treatment was estimated using the formula proposed by Henderson and Tilton (1955), which allows comparing the population dynamics between treatments and absolute control, correcting for possible natural variations. The T4 treatment was the most efficient, followed by T3 and T2 treatments ($p<0.05$) (Table 3). The reduction of *S. frugiperda* larvae observed after the application of capsaicin as a treatment could be due to its action as a toxic and repellent agent (Ileer *et al*., 2022), this shows that the ability of capsaicin to modulate the activity of the larval nervous system constitutes a relevant mechanism of action, which supports its potential application as a bioactive agent in integrated pest management strategies.

Corn yield

The yield of the corn crop showed statistically significant differences ($p<0.05$) between treatments (Table 4), with an increasing trend associated with capsaicin concentration. The T4 treatment achieved the highest yield. The T4, T3, and T2 treatments formed a statistically different group compared to the T6, while T1 and T5 showed intermediate yields.

The T3 and T4 treatments caused a notable decrease in the levels of *S. frugiperda* infestation. These findings coincide with those obtained by Zelaya-Molina *et al.* (2022), who showed that capsaicin significantly reduces infestation in tomato (*S. lycopersicum*) and cucumber (*C. sativus*) crops.

Table 4. Average yield of corn crop (*Z. mays*) var. Blanco Urubamba (t.ha^{-1}) under different capsaicin treatments.

Treatments	Yield (t.ha^{-1})
T1 (Capsaicin, 6.70 mL.L^{-1})	11.56 ± 0.11 bc
T2 (Capsaicin, 10.05 mL.L^{-1})	12.04 ± 0.14 ab
T3 (Capsaicin, 13.40 mL.L^{-1})	14.09 ± 0.12 ab
T4 (Capsaicin, 16.75 mL.L^{-1})	17.12 ± 0.15 a
T5 (Rocoto pepper extract)	11.43 ± 0.09 bc
T6 (Absolute control)	9.31 ± 0.12 c

C.V. (%): 3.28; p-value <0.05. Same letters indicate treatments without statistically significant differences, according to Tukey at 5 %.

In turn, these results are supported by what was stated by Sinha *et al*. (2011), who pointed out that capsaicin eliminates various invertebrates.

After the first application (80 das), a significant increase in the efficacy of T4 treatment for controlling *S. frugiperda* larvae was observed. The differences found could be associated with environmental factors, which, according to Zelaya-Molina *et al*. (2022), directly influence the ability of *S. frugiperda* to cause damage to corn crops. Similarly, Cabrera *et al.* (2016) reported that formulations of natural origin helped to reduce the incidence of the green leafhopper (*Empoasca kraemeri,* Ross, and Moore).

Conclusions

The application of water-soluble capsaicin proved to be highly effective in the control of *Spodoptera frugiperda* in corn (Zea mays L.) var. Blanco Urubamba, highlighting the dose of 16.75 mL.L^{-1} for

Table 3. Efficacy in the control of *Spodoptera frugiperda larvae i*n corn (*Zea mays* L.) var. Blanco Urubamba, post-application of the treatments.

Treatment	Efficacy in the control of *Spodoptera frugiperda* larvae (%)				
	Days after sowing (das)				
	80	90	100	110	120
T1 (capsaicin 6.70 mL.L^{-1})	33.58 d	44.13 d	61.77 d	62.78 b	78.30 bc
T2 (capsaicin 10.05 mL.L^{-1})	42.58 c	52.43 c	68.62 c	72.91 ab	85.19 abc
T3 (capsaicin 13.40 mL.L^{-1})	50.06 b	59.02 b	74.56 b	73.97 ab	93.83 ab
T4 (capsaicin 16.75 mL.L^{-1})	60.57 a	68.21 a	78.32 a	85.21 a	96.69 a
T5 (Rocoto pepper extract)	30.67 d	41.92 d	59.29 d	62.51 b	72.86 bc
CV (%)	3.05	3.42	3.78	12.32	11.42
Sx: ±	0.11	0.10	0.08	0.16	0.21
p-value	0.003	0.003	0.003	0.003	0.003

Means with a common letter are not different ($p>0.05$).

its ability to reduce larval density and infestation, which resulted in a significant increase in yield. These results show its potential as a sustainable alternative to conventional chemical insecticides, providing both agronomic and environmental benefits.

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