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Research Article

Keywords: Biopesticide, dose response, incidence, severity index, phytotoxicity

Posted Date: June 25th, 2026

DOI: <https://doi.org/10.21203/rs.3.rs-9847685/v1>

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**Efficacy of *Trichoderma koningiopsis* Th003 in the control of anthracnose
(*Colletotrichum* sp.) in Hass avocado (*Persea americana* Mill.) under field conditions**

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ABSTRACT

Hass avocado is established as a fundamental pillar of global agricultural trade, with market
projections showing sustained growth toward the end of the decade. In Colombia, the
industry has achieved notable expansion in both cultivated area and total export value, its
competitiveness is threatened by anthracnose (*Colletotrichum* spp.), which causes high
rejection rates in international markets. This study evaluated the field efficacy of a
biopesticide based on *Trichoderma koningiopsis* Th003 for anthracnose management in two
commercial orchards in Popayán and San Vicente Ferrer, Colombia. Four doses (1.5, 1.0, 0.5,
and 0.1 g L⁻¹) were applied as foliar sprays at 15-day intervals over a six-month period.
Disease incidence and severity were assessed at fruit phenological stages 712, 715, and 719,

and phytotoxicity was additionally evaluated at 3 g L⁻¹. No anthracnose incidence was detected at stage 712. Disease pressure increased markedly thereafter, reaching 100% incidence at harvest (stage 719). Under these conditions, the severity index was the most informative variable for differentiating treatment performance. The 1.5 and 1.0 g L⁻¹ doses consistently showed the lowest severity values at stages 715 and 719, with a clear positive dose response pattern. At harvest, the 1.5 g L⁻¹ dose achieved efficacy values of 56% in San Vicente Ferrer and 43% in Popayán, whereas the 1.0 g L⁻¹ dose reached 35% and 29%, respectively. No phytotoxic effects were observed at 3 g L⁻¹. These results support the use of *T. koningiopsis* Th003, particularly at 1.5 and 1.0 g L⁻¹, as a biological option for crop integrated management.

Keywords: Biopesticide, dose response, incidence, severity index, phytotoxicity.

INTRODUCTION

Avocado (*Persea americana* Mill.) is a globally important fruit crop whose production and trade have expanded markedly in recent years. According to FAOSTAT, global avocado production reached approximately 11.35 million metric tons in 2024 (FAOSTAT 2025), while the Food and Agriculture Organization (FAO) estimated that global avocado exports rose by 13 percent to 3.3 million tonnes in 2025, positioning avocado among the most actively traded major tropical fruits worldwide. (FAO 2025).

In Colombia, avocado cultivation has established itself as one of the most important crops, with approximately 40,000 hectares planted in 2025 primarily in the departments of Antioquia, the Coffee Axis, Tolima, Huila, Cauca, and Valle del Cauca, with an estimated harvest of 206,352 tons, the country exported more than 201,000 tons in the same year, generating revenues close to US\$375 million. Europe remains the primary destination for Colombian avocados, accounting for 60% of total exports (with a value of US\$134.2 million and a growth of 10.8% compared to 2024), where the Netherlands is the largest buyer, holding a 35.8% market share (AnalDEX 2025).

However, the productivity and competitiveness of Hass avocado are affected by various phytosanitary limitations, with anthracnose, caused by the *Colletotrichum* spp. species complex, being one of the most significant. This disease has a wide geographical distribution, causing economic losses in all avocado-growing regions. The pathogen not only induces direct yield losses by infecting vegetative and reproductive structures but also drastically affects postharvest quality. *Colletotrichum* sp., can infect the fruit in the field and remain quiescent until environmental or physiological conditions favor symptom expression (Law et al. 2025). This behavior makes anthracnose especially difficult to manage, as visible symptoms may develop during advanced stages of fruit development or near harvest, when losses are directly associated with the degradation of fruit quality and reduced marketability, reporting rejection rates of up to 52.5% in Colombian packing houses, which generates significant economic losses (Jaramillo et al. 2023; Ramírez-Gil et al. 2020; Bernal et al. 2025).

Conventionally, the primary method for controlling *Colletotrichum* sp., has been the application of synthetic chemical fungicides, employing a variety of active ingredients such as azoxystrobin, difenoconazole, fludioxonil, prochloraz (with limited use in avocado), and thiabendazole, which have allowed for the mitigation of negative impacts on yields (Bernal et al. 2025). However, the risk of adverse effects on the environment and human health, coupled with the loss of biological efficacy in the field and increasing regulatory restrictions on the use of certain active ingredients (Hejazi et al. 2022; Bernal et al. 2025; Codex Alimentarius 2025), has sparked interest in unconventional control methods (Diallo et al. 2021; Choudhary et al. 2025).

Under this scenario of transition toward sustainable agriculture, it has become imperative to validate effective biological alternatives, such as the use of biopesticides formulated from antagonistic microorganisms. These alternatives allow for the mitigation of the disease's impact without compromising the safety of the final product or its competitiveness in international markets (Bernal et al. 2025).

Among the most outstanding antagonists the species of the genus *Trichoderma* have been extensively studied as biological control agents because they can suppress plant pathogens through multiple mechanisms, including competition for nutrients and space, mycoparasitism, antibiosis, enzymatic degradation of pathogen structures, and induction of plant defense responses (Oyesola et al. 2024; Guzmán-Guzmán et al. 2025).

In avocado, *Trichoderma* strains have shown promising potential for disease management. López-López et al. (2023) reported strong antagonistic activity of native isolates against

important avocado fruit pathogens, including *Colletotrichum gloeosporioides*. More recently, Chamarro-Anaya et al. (2025) demonstrated that native *Trichoderma* strains isolated from avocado crops significantly inhibited *C. gloeosporioides in vitro* and promoted avocado plant growth. Evidence specifically involving *T. koningiopsis* in avocado was reported by Andrade-Hoyos et al. (2020), who identified two endophytic strains of this species (T-K8 and T-K11) and showed under greenhouse conditions that *Trichoderma* treatments, which included these isolates, reduced wilt symptoms and seedling death caused by *Phytophthora cinnamomi*.

Among the *Trichoderma* species with demonstrated biocontrol potential, *Trichoderma koningiopsis* Th003, the active ingredient of biopesticide Tricotec® WG, has shown biological and agronomic attributes that support its integration into crop protection programs, including rapid growth, adaptability to different environmental conditions, and compatibility with pesticides commonly used in agricultural systems. Previous studies have reported its effectiveness against economically important fungal pathogens, supporting its potential integration into disease management programs (Moreno Velandia et al. 2020; Zapata Narváez et al. 2023; Zapata-Narváez and Botina-Azain 2023).

Despite this accumulated evidence, information regarding the field performance of *T. koningiopsis* Th003 specifically for the management of anthracnose in Hass avocado under commercial conditions remains limited. Therefore, the objective of this study was to determine the field efficacy of Tricotec® WG (*Trichoderma koningiopsis* Th003) in reducing the severity of anthracnose in Hass avocado fruits.

MATERIAL AND METHODS

Field sites

The study was conducted between November 2024 and June 2025 in two commercial Hass avocado orchards in Colombia, which focus on oil production and fruit supply for the domestic market. The first fruit orchard was in Popayán, Cauca, a city situated in southwestern Colombia, between the western and central mountain ranges of the Andes (1,874 m above sea level). The second orchard was in San Vicente Ferrer, a municipality located in the Eastern subregion of the department of Antioquia (Colombia), in the Central Mountain Range (2,270 m above sea level).

Treatments and applications

Four doses of the biopesticide based on *T. koningiopsis* Th003, were evaluated: 1.5 g L⁻¹ (1.5 × 10⁶ conidia mL⁻¹), 1.0 g L⁻¹ (1 × 10⁶ conidia mL⁻¹), 0.5 g L⁻¹ (5 × 10⁵ conidia mL⁻¹), and 0.1 g L⁻¹ (1 × 10⁵ conidia mL⁻¹) determining its efficacy relative to untreated control.

The trial was established using a Randomized Complete Block Design (RCBD) with four replicates. The experimental unit consisted of three trees, on which four branches were marked (according to the cardinal points: North, South, East, and West). From each branch, five fruits were evaluated, for a total of 240 fruits per treatment. For each treatment, the necessary amount of biopesticide was prepared according to the evaluated dose and

dispensed into 20-liter capacity backpack sprayers for application. The aerial part of the trees was sprayed, covering branches, leaves, flowers, and fruits, with an application frequency of every fifteen days for six months, using an application volume of 1.5 liters per tree.

Disease assessment and efficacy calculation

Disease assessments were performed three times during fruit development. The first assessment was conducted one month after trial establishment on fruits at phenological stage 712 (first fruitlet abscission), according to the scale described by Alcaraz et al. (2013). The second assessment was conducted three months after trial establishment on fruits at phenological stage 715 (50% of final fruit size). The third assessment was conducted at harvest on fruits at phenological stage 719 (90% or more of final fruit size). In the final evaluation.

At each evaluation, disease incidence and severity were recorded. Incidence was calculated as the percentage of fruits showing symptoms associated with anthracnose damage, according to Equation (1).

$$\text{Incidence(\%)} = \left(\frac{\text{number of symptomatic fruits}}{\text{total number of fruits evaluated}} \right) \times 100 \quad (1)$$

Disease severity was assessed using a visual scale for lenticel anthracnose lesions (symptoms often manifest as lenticel-centered lesions, where the infection radiates from the lenticels,

forming circular, sunken brown-to-black spots as the fruit ripens) described by Grisales et al. (2016). Severity classes were defined according to the estimated percentage of fruit surface affected as follows: grade 0, 0% (no visible symptoms); grade 1, 0.1–1.9% (first visible lesions, consisting of small brown to black spots); grade 2, 2–5.9% (slightly larger or more numerous lesions, still within the tolerance threshold); grade 3, 6–10.9% (intermediate severity, with darker lesions that may begin to crack); grade 4, 11–49.9% (moderately severe lesions affecting up to nearly half of the fruit epidermis); and grade 5, 50–100% (severe damage, with extensive lesion coverage on the fruit surface). Based on these ratings, a severity index (SI) was calculated according to Equation (2).

$$SI = \frac{\sum(n_i \times s_i)}{N} \quad (2)$$

Where n_i is the number of fruits in each severity class, s_i is the severity score of that class, and N is the total number of fruits evaluated.

The efficacy of *T. koningiopsis* Th003 was estimated from severity index values using Abbott's formula, as shown in Equation (3):

$$\text{Efficacy}(\%) = \left(\frac{C - T}{C} \right) \times 100 \quad (3)$$

where C is the severity index of the untreated control and T is the severity index of each treatment.

Phytotoxicity assessment

Phytotoxic effects of biopesticide on Hass avocado fruits were evaluated by visual inspection at all four tested doses in both locations. In addition, phytotoxicity was assessed at a higher dose of 3 g L⁻¹ (3×10^6 conidia mL⁻¹), using the same experimental unit structure as three trees, but with two replicates. In this essay, external color changes were visually assessed in 20 fruits per experimental unit. Phytotoxicity was classified according to the severity scale shown in Table 1, adapted from EWRS (Champion, 2000).

Table 1. Visual severity scale used to assess phytotoxic effects on Hass avocado fruits (modified from EWRS; Champion, 2000).

Level	Descriptor
0	Absence of symptoms
1	Trace symptoms of chlorosis
2	Slight symptoms, chlorosis
3	Spots or strong discoloration
4	Heavy spotting extensively distributed

Statistical analysis

Disease incidence and severity data were subjected to an analysis of variance (ANOVA), and means were compared using Fisher's LSD test ($\alpha = 0.05$).

RESULTS

No incidence of anthracnose was observed in fruits at phenological stage 712 in any of the treatments for either location. In contrast, at stage 715 in the San Vicente Ferrer location, significant statistical differences were observed between treatments; the control presented the lowest incidence (87%), while the application of 1 g L⁻¹ of the biopesticide reported the highest disease incidence (98%, Fig. 1). Meanwhile, for the Popayán location, no significant differences were found between treatments, with an observed incidence ranging between 99% and 100%.

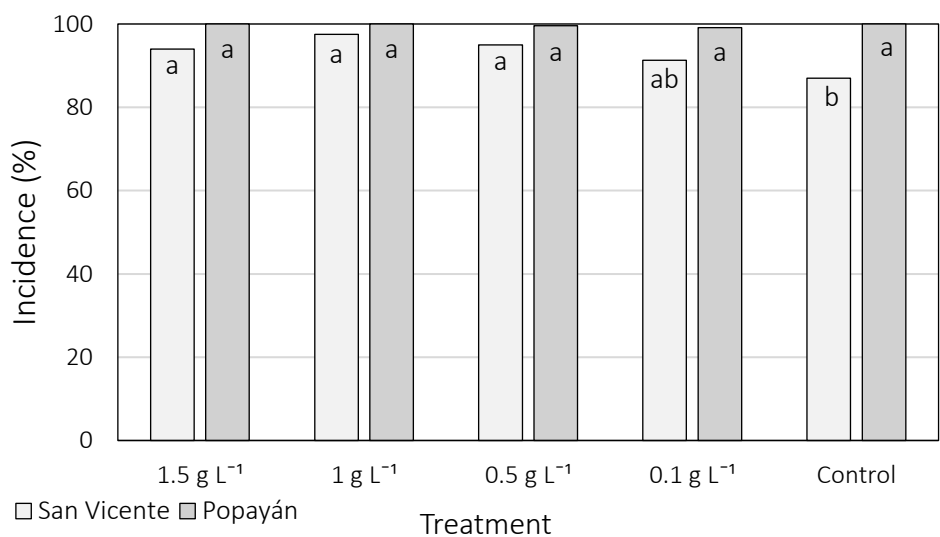


Fig. 1 Anthracnose incidence in Hass avocado fruits at phenological stage 715. Letters indicate significant differences according to Fisher's LSD test ($p < 0.05$).

Regarding the severity index (SI) in fruits at phenological stage 715, in the San Vicente Ferrer location, the untreated control (SI = 1.15) and the 1.5 g L⁻¹ dose (SI = 1.17) exhibited the

lowest levels, showing significant statistical differences compared to the rest of the treatments (Figure 3). Meanwhile, in Popayán, the 1.5 g L⁻¹ dose was significantly distinguished by recording the lowest severity (SI = 2), whereas the highest impact occurred with the control, which reached an SI= 3.5 (Fig. 3).

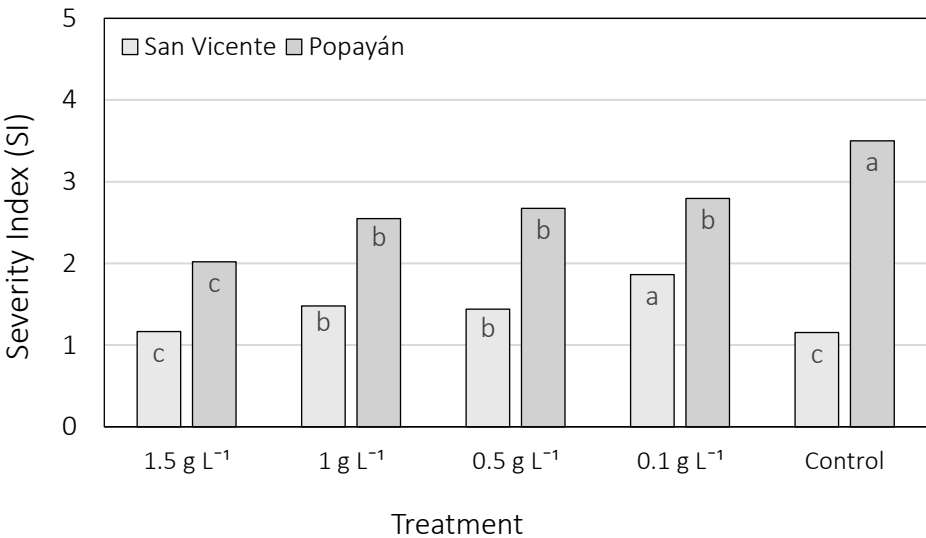


Fig. 2 Severity index for anthracnose in avocado fruits at phenological stage 715. Letters indicate significant differences according to Fisher's LSD test (p < 0.05).

The incidence of anthracnose in fruits at phenological stage 719 was 100% in both locations (Fig. 3).

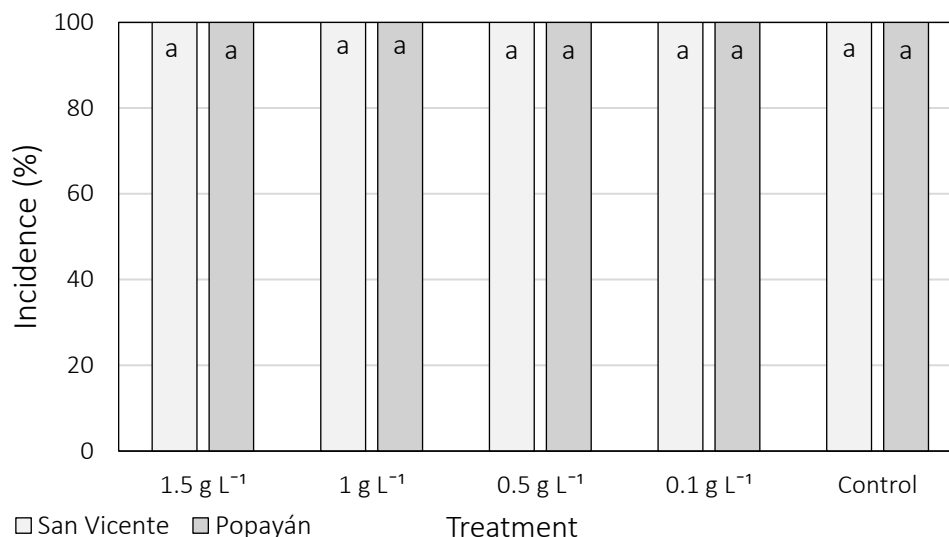


Fig. 3 Anthracnose incidence in Hass avocado fruits at phenological stage 719. Letters indicate significant differences according to Fisher's LSD test ($p < 0.05$).

Regarding severity in fruits at phenological stage 719, the location of San Vicente Ferrer showed the lowest SI (1.6) with the 1.5 g L⁻¹ dose, which was significantly different from the other treatments. This was followed by the 1 g L⁻¹ dose (SI = 2.4), while the control recorded the highest severity with a value of 3.7 (Fig. 4). In Popayán, the trend was similar: the 1.5 g L⁻¹ dose achieved the lowest severity (SI = 2.7), showing significant differences from the rest, followed by the 1 g L dose (SI = 3.4). The highest disease index in this location was reported with a 0.1 g L⁻¹ dose, reaching an SI of 4.2 (Fig. 4).

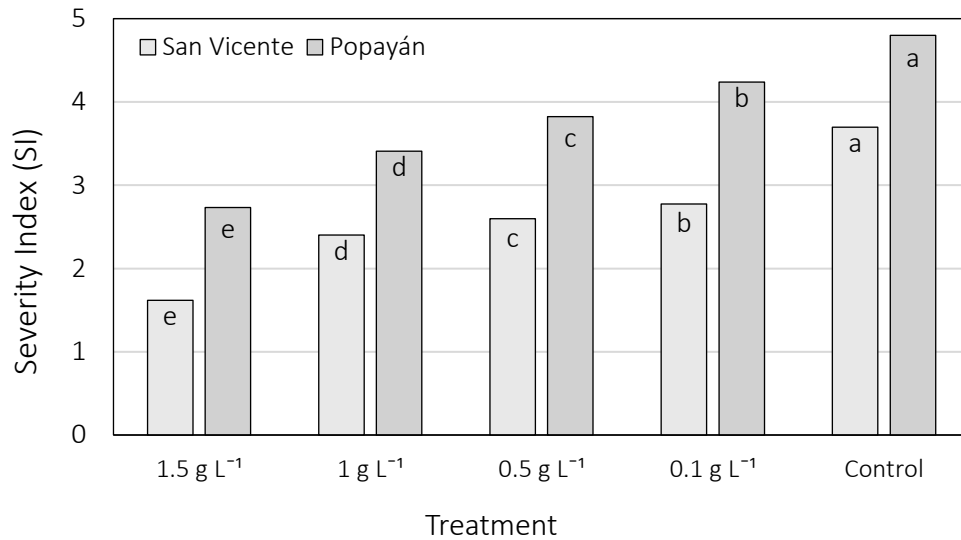


Fig. 4 Severity index for anthracnose in avocado fruits at phenological stage 719. Letters indicate significant differences according to Fisher's LSD test ($p < 0.05$).

Efficacy of Tricotec® WG in the control of anthracnose in Hass avocado fruits

The application of the biopesticide based on *T. koningiopsis* Th003 doses of 1.5 g L⁻¹ and 1 g L⁻¹ proved to be the most effective in reducing the severity of anthracnose in Hass avocado fruits (stage 719). With the higher dose, an efficacy of 56% was achieved in San Vicente and 43% in Popayán, while the 1 g L⁻¹ dose reached 35% and 29%, respectively. Furthermore, a direct relationship between dose and effectiveness was observed, as efficacy decreased as the biopesticide dose was reduced (Fig. 5). This result is particularly relevant given that the greatest damage caused by the disease was recorded at this stage.

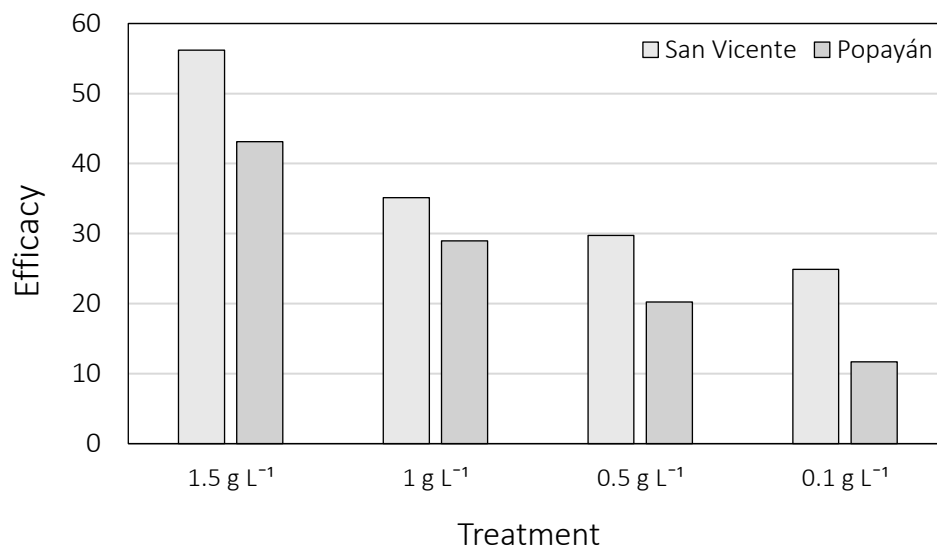


Fig. 5 Efficacy of the evaluated doses of the biopesticide based on *T. koningiopsis* Th003 controlling anthracnose in Hass avocado fruits at phenological stage 719.

Phytotoxicity assessment

No phytotoxic effects were observed in fruits treated with the biopesticide at any of the evaluated doses in either orchard. Likewise, fruits exposed to the additional 3 g L⁻¹ dose showed no visible external color changes or symptoms of damage, and all observations were classified as grade 0 according to the phytotoxicity scale shown in Table 1. Representative fruits from the 3 g L⁻¹ treatment retained a healthy appearance and showed no visible alterations in external color (Fig. 6). These observations indicate that the product did not cause visible injury to Hass avocado fruits, even at a dose above the range evaluated for disease management.



Fig. 6 External appearance of Hass avocado fruits treated with the biopesticide based on *T. koningiopsis* Th003 at 3 g L⁻¹ during phytotoxicity assessment.

DISCUSSION

The results obtained in both locations showed that anthracnose pressure became extremely high as fruit development progressed. Although no disease incidence was detected at stage 712, incidence increased sharply at stage 715 and reached 100% at harvest (stage 719) in both orchards. This pattern is consistent with the epidemiological behavior of *Colletotrichum* in avocado, in which infections may remain quiescent during early stages of fruit development and become evident as fruit maturity advances and environmental conditions favor symptom expression (Dowling et al., 2020). Under such conditions, symptom presence becomes almost generalized, and incidence loses discriminatory power among treatments. In the present study, this was particularly evident at harvest, when all treatments reached complete incidence and treatment differences were expressed mainly through severity. This interpretation is consistent with reports from commercial Hass avocado orchards in Colombia, where anthracnose and lenticel damage were identified among the most relevant postharvest problems, and where disease expression was associated with multiple preharvest

293 agronomical factors (Ramírez-Gil et al., 2021). This was further compounded by the constant
294 rainfall recorded during the final four months of the trial in both locations (averaging 303
295 mm in San Vicente and 233 mm in Popayán) (IDEAM, 2026), which contributed to
296 maintaining an environment conducive to pathogen development, particularly high relative
297 humidity within the tree canopy (Dowling et al., 2020).

298
299 Given this scenario, the severity index (SI) was the parameter that allowed for the
300 differentiation of the performance of the evaluated biopesticide doses in reducing damage or
301 disease spread in fruits that were already infected or contained quiescent infections (Dowling
302 et al. 2020). At both phenological stages 715 and 719, the 1.5 g L⁻¹ and 1 g L⁻¹ doses of the
303 biopesticide consistently showed the lowest disease severity, while the lowest dose showed
304 the poorest performance. This indicates that the principal effect of the biopesticide was not
305 to prevent symptom occurrence completely, but to reduce lesion development and therefore
306 the extent of visible damage on the fruit surface. From a biological and agronomic standpoint,
307 this is highly relevant because in Hass avocado, external lesion severity directly affects fruit
308 appearance, commercial acceptability, and the probability of rejection during
309 commercialization. The fact that severity remained responsive while incidence saturated
310 highlights the importance of prioritizing this variable when evaluating biological alternatives
311 under high disease pressure.

312
313 A clear positive dose-response relationship was observed in both locations, where a higher
314 concentration of the biopesticide translated into greater efficacy, which progressively
315 decreased as the dose was reduced. These results indicate that the biological activity of *T.*
316 *koningiopsis* Th003 was dose dependent under commercial conditions, and that the two

highest doses had the greatest capacity to limit anthracnose severity during the most critical stage for fruit quality. This pattern reinforces the view that, under sustained disease pressure, the most meaningful outcome of biocontrol is often the attenuation of disease development rather than complete exclusion of infection.

The present results are consistent with the broader literature on *Trichoderma* as a biological control genus, but they also extend it in an important way. Previous work in avocado has shown that native *Trichoderma* isolates can strongly antagonize fruit pathogens under controlled conditions. López-López et al. (2023) reported high antagonistic activity of native isolates against *Colletotrichum gloeosporioides* and other avocado fruit pathogens and linked their effect to increased glucanase and chitinase activity in fruit assays. Likewise, Chamarro-Anaya et al. (2025) showed that native *Trichoderma* strains isolated from avocado crops inhibited *C. gloeosporioides* in vitro, although their strongest results were associated with *T. harzianum* and *T. viride* rather than *T. koningiopsis*. These studies support the biological plausibility of *Trichoderma* based disease suppression in avocado, but they were not conducted under commercial field conditions.

Evidence involving *T. koningiopsis* in avocado has also been reported under greenhouse conditions. Andrade-Hoyos et al. (2020) identified two endophytic strains of *T. koningiopsis* (T K8 and T K11) and showed that *Trichoderma* treatments reduced wilt symptoms and seedling death caused by *Phytophthora cinnamomi*. However, those results were obtained in seedlings under greenhouse conditions and involved a soilborne oomycete rather than a fruit anthracnose pathosystem. Thus, while they support the relevance of *T. koningiopsis* as a beneficial antagonist in avocado, they do not directly address fruit disease suppression under

orchard conditions. In this sense, the present study adds field-based evidence showing that repeated canopy applications of a *T. koningiopsis* based biopesticide can reduce anthracnose severity in commercial Hass avocado orchards.

An additional point that strengthens the interpretation of the present results is that *Trichoderma* performance in avocado cannot be inferred solely from in vitro antagonism or endophytic establishment. Salcedo-Sarmiento et al. (2025), working with *Trichoderma* against the laurel wilt pathogen in avocado, reported strong in vitro inhibition and some endophytic colonization, but no significant disease suppression after inoculation of precolonized seedlings. This illustrates that expression of biocontrol activity depends strongly on the pathosystem, the formulation, the inoculation route, and the application strategy. In contrast, the present study showed that under repeated foliar applications during fruit development, *T. koningiopsis* Th003 was able to express a measurable protective effect against anthracnose under field conditions

From a practical perspective, the consistency of the 1.5 and 1.0 g L⁻¹ doses across the two locations indicates that both concentrations have potential for integration into disease management programs, with 1.5 g L⁻¹ providing the strongest and most stable response. The absence of phytotoxicity at all tested doses, including 3 g L⁻¹, further reinforces the agronomic relevance of these results, since it shows that the doses with the best disease suppression were also visually safe for the fruit. This is especially important in Hass avocado production, where external appearance is directly linked to fruit quality perception and commercial value. Taken together, the results support the use of *T. koningiopsis* Th003 as a

promising biological tool for reducing anthracnose severity in commercial Hass avocado orchards, particularly at 1.5 and 1.0 g L⁻¹

CONCLUSIONS

Anthracnose pressure, measured as incidence, was extremely high as fruit development progressed, particularly in the advanced phenological stages. As a result, disease incidence was a limited factor for discriminating treatment performance, whereas severity was the variable that allowed for determining the effect of *T. koningiopsis* Th003 on fruit damage.

In both locations, the 1.5 g L⁻¹ and 1 g L⁻¹ doses of the biopesticide showed the best performance in reducing disease severity. These results suggest that the bioproduct is more effective at limiting the progression of lesions than at preventing the initial infection

The positive dose-response pattern observed throughout the trial supports the agronomic relevance of the two highest doses, particularly 1.5 g L⁻¹, which provided the most stable reduction in severity. The 1 g L⁻¹ dose also showed favorable performance and may represent an operationally useful alternative depending on prevailing weather conditions and disease pressure.

This study also provides field-based evidence to the current literature on the use of *Trichoderma* in avocado, which has been predominantly dominated by *in vitro*, post-harvest, or greenhouse studies. Therefore, these results strengthen the case for *T. koningiopsis* Th003

as a biologically based option to be integrated into integrated crop management programs to reduce anthracnose in avocado orchards.

No phytotoxic effects were observed in Hass avocado fruits treated with the biopesticide at any of the evaluated doses, including 3 g L⁻¹. This supports the practical feasibility of using the product under field conditions and reinforces its potential incorporation into integrated anthracnose management programs for Hass avocado production.

ACKNOWLEDGMENTS

The authors would like to thank the Ministry of Science, Technology, and Innovation of Colombia (Minciencias) and the Corporación Colombiana de Investigación Agropecuaria (AGROSAVIA) for funding the project 'BIOFLORHASS: Innovation and technological cooperation program for the development of biological control strategies for rose and Hass avocado crops in Colombia', under grant number [80740-469-2021], which enabled the development of this work.

Author contribution statement.

Y.A. Zapata Narváez: Conceptualization, Methodology, Data curation, Formal analysis, Writing (original draft), Writing (review and editing). L.N. Martínez: Field data acquisition, Data curation. J.L. Castro Mayorga: Investigation, Field data acquisition, Writing (review and editing), Project administration, Funding acquisition. M. Gómez: Supervision, Project administration, Funding acquisition, Writing (review and editing).

Ethics and Conflict of Interest Statement.

The authors declare that the research work *Efficacy of Trichoderma koningiopsis Th003 in the control of anthracnose (Colletotrichum sp.) in Hass avocado (Persea americana Mill.) under field conditions* did not require the participation of human subjects or animals; therefore, approval from a medical or social ethics committee was not required. Furthermore, the authors formally declare that there is no conflict of interest of a financial, personal, or professional nature that could have influenced the development of this work or the presentation of its results.

REFERENCIAS.

Alcaraz M, Thorp T, Hormaza J (2013) Phenological growth stages of avocado (*Persea americana*) according to the bbch scale. *Scientia Horticulturae*, 164, 434-439.

<https://doi.org/10.1016/j.scienta.2013.09.051>

Andrade-Hoyos P, Silva-Rojas HV, Romero-Arenas O (2020) Endophytic *Trichoderma* Species Isolated from *Persea americana* and *Cinnamomum verum* Roots Reduce Symptoms Caused by *Phytophthora cinnamomi* in Avocado. *Plants*, 9(9), 1220. <https://doi.org/10.3390/plants9091220>

Asociación Nacional de Comercio Exterior - Analdex (2025) Exportaciones de aguacate crecieron un 21,3% durante 2025.

<https://analdex.org/2026/02/25/exportaciones-de-aguacate-crecieron-un-213-durante-2025/#:~:text=Con%20cifras%20de%20la%20Dian,2024%2C%20cuando%20fueron%2013.315%20toneladas>

438

439 Asociación Nacional de Empresarios de Colombia – ANDI and Instituto Colombiano
440 Agropecuario – ICA (2015) Manual para elaboración de protocolos para ensayos de eficacia
441 con PQUA. ICA. 110 p.

442 [https://www.ica.gov.co/areas/agricola/servicios/regulacion-y-control-de-plaguicidas-](https://www.ica.gov.co/areas/agricola/servicios/regulacion-y-control-de-plaguicidas-quimicos/manual-protocolos-ensayos-eficacia-pqua-1.aspx)
443 [quimicos/manual-protocolos-ensayos-eficacia-pqua-1.aspx](https://www.ica.gov.co/areas/agricola/servicios/regulacion-y-control-de-plaguicidas-quimicos/manual-protocolos-ensayos-eficacia-pqua-1.aspx)

444

445 Avocado Market Size and Outlook (2023) Glob. Avocado Mark. Size Outlook 2023–2030.
446 Available online at: [https://www.grandviewresearch.com/industry-analysis/fresh-avocado-](https://www.grandviewresearch.com/industry-analysis/fresh-avocado-market-report)
447 [market-report](https://www.grandviewresearch.com/industry-analysis/fresh-avocado-market-report) (Accessed April 10, 2026).

448

449 Bernal VV, Boeckman NJ, Aćimović SG, Khodadadi F (2025) The dark side of avocados: a
450 review of anthracnose and stem-end rot in postharvest fruit. *Front. Microbiol.* 16:1644061.
451 <https://doi.org/10.3389/fmicb.2025.1644061>

452

453 Chamarro-Anaya L, Barboza-García A, Baldiris-Avila R, Montes-Robledo A
454 (2025) Utilizing *Trichoderma spp.* as an alternative for the promotion of plant growth and
455 the control of anthracnose in avocado crops. *Asian Journal of Mycology*, 8(1), 129-140.
456 https://www.asianjournalofmycology.org/pdf/AJOM_8_1_9-1.pdf

457

458 Champion G. T (2000) Bright and the field scale evaluations herbicides tolerant. G. M. Trials.
459 AICC Newsletter.

460 [https://repository.rothamsted.ac.uk/item/88746/bright-and-field-scale-evaluations-](https://repository.rothamsted.ac.uk/item/88746/bright-and-field-scale-evaluations-herbicide-tolerant-gm-trials)
461 [herbicide-tolerant-gm-trials](https://repository.rothamsted.ac.uk/item/88746/bright-and-field-scale-evaluations-herbicide-tolerant-gm-trials)

462

463 Choudhary H, Dhar V, Dave P, Pareek S (2025) Postharvest anthracnose disease in mango
464 (*Mangifera indica* L.) fruit: Sustainable alternatives for the control. *Crop Science*, 65,
465 e70064. <https://doi.org/10.1002/csc2.70064>

466

467 Codex Alimentarius. Codex Pesticides Residues in Food Online Database (2025).
468 [https://www.fao.org/fao-who-codexalimentarius/codex-texts/dbs/pestres/commodities-](https://www.fao.org/fao-who-codexalimentarius/codex-texts/dbs/pestres/commodities-detail/es/?c_id=130)
469 [detail/es/?c_id=130](https://www.fao.org/fao-who-codexalimentarius/codex-texts/dbs/pestres/commodities-detail/es/?c_id=130)

470

471 Diallo Y, Diedhiou PM, Bush E, Nita M, Baudoin A (2021) Antifungal activity of some
472 alternative control against mango anthracnose in Senegal. *International Journal for*
473 *Innovation Education and Research*, 9(2), 239-
474 246. <https://doi.org/10.31686/ijer.vol9.iss2.2949>

475

476 Dowling M, Peres N, Villani S, Schnabel G (2020) *Colletotrichum* on Fruit Crops: A
477 “Complex” Challenge. *Plant Disease*. 104:(9), 2301-2316. [https://doi.org/10.1094/PDIS-11-](https://doi.org/10.1094/PDIS-11-19-2378-FE)
478 [19-2378-FE](https://doi.org/10.1094/PDIS-11-19-2378-FE)

479

480 FAO (2026) Major Tropical Fruits Market Review. Preliminary results 2025. Rome.
481 <https://openknowledge.fao.org/handle/20.500.14283/cd8314en>

482

483 FAOSTAT (2025) *Crops and Livestock Products (Avocados, production quantity, 2024)*.
484 Food and Agriculture Organization of the United Nations.
485 <https://www.fao.org/faostat/en/#data->

486

487 Guzmán-Guzmán P, Etesami H, Santoyo G (2025) *Trichoderma*: a multifunctional agent in
488 plant health and microbiome interactions. *BMC microbiology*, 25(1), 434.
489 <https://doi.org/10.1186/s12866-025-04158-2>

490

491 Hejazi M, Grant JH, Peterson E (2022) Trade impact of maximum residue limits in fresh
492 fruits and vegetables. *Food Policy*, 106, 102203.
493 <https://doi.org/10.1016/j.foodpol.2021.102203>

494

495 Instituto de Hidrología, Meteorología y Estudios Ambientales – IDEAM.
496 Hydrometeorological data for Peñón (Antioquia) and Cauca. Query performed 13-03-2026
497 from: <http://dhime.ideam.gov.co/atencionciudadano/>

498

499 Jaramillo-Laverde A, Murcia-Riaño N, Martínez, M, Ceballos-Aguirre G, Martínez-
500 Caballero LN, Ángel-García C, Rodríguez-Arévalo KA (2023). Identificación y manejo de
501 enfermedades que afectan la calidad comercial del fruto de aguacate (*Persea americana*
502 Mill.) cv. Hass. Mosquera (Colombia). Agrosavia.
503 <https://doi.org/10.21930/agrosavia.analisis.7406702>

504

505 Law C. X., Hashim, N., Ismail, S. I., Jahari, M., & Al Riza, D. F. (2025). A review on
506 anthracnose disease caused by *Colletotrichum* spp. in fruits and advances in control
507 strategies. *International journal of food microbiology*, 442, 111397.
508 <https://doi.org/10.1016/j.ijfoodmicro.2025.111397>

509

López-López ME, Toro-Sánchez CL, Ochoa-Ascencio S, Aguilar-López JA, Martínez-Cruz O, Madrigal-Pulido JA et al 2023. Antagonismo de cepas de *Trichoderma* aisladas en Tanaxuri, Michoacán, México contra patógenos postcosecha del fruto de aguacate (*Persea americana* Mill). *Biotecnia*, 25(1), 24-33.

<https://doi.org/10.18633/biotecnia.v25i1.1726>

Moreno-Velandia CA, Izquierdo-García LF, Zapata-Narváez YA, Beltrán-Acosta CR, Zuluaga-Mogollón MV (2020) Tricotec® WG Biofungicida. Recomendaciones de uso y patógenos blanco. Corporación Colombiana de Investigación Agropecuaria–AGROSAVIA. 48 p. <http://hdl.handle.net/20.500.12324/36526>

Oyesola OL, Tonjock RK, Bello AO, Taiwo OS, Obembe OO (2024) *Trichoderma*: A Review of Its Mechanisms of Action in Plant Disease Control. Preprints. <https://doi.org/10.20944/preprints202405.1378.v1>

Ramírez-Gil JG, López JH, Henao-Rojas JC (2020) Causes of Hass avocado fruit rejection in preharvest, harvest, and packinghouse: economic losses and associated variables. *Agronomy*10:8. <https://doi.org/10.3390/agronomy10010008>

Salcedo-Sarmiento S, Soares J, De Cote JA, Monte E, Gazis R (2025) Antibiosis, endophytic colonization, and efficacy of *Trichoderma* against the laurel wilt pathogen in avocado. *PhytoFrontiers*. 6:61-71. <https://doi.org/10.1094/PHYTOFR-04-25-0036-R>

533 Trinidad-Ángel E, Ascencio-Valle F, Ulloa JA, Ramírez-Ramírez JC, Ragazzo-Sánchez, JA,
534 Calderón-Santoyo M, Bautista-Rosales PU (2017) Identificación y caracterización de
535 *Colletotrichum* spp. Causante de antracnosis en aguacate Nayarit, México. *Revista mexicana*
536 *de ciencias agrícolas*, 8(spe19), 3953-3964. <https://doi.org/10.29312/remexca.v0i19.664>
537

538 Zapata-Narváez YA, Botina-Azain BL (2023) Effect of adjuvants, fungicides and
539 insecticides on the growth of *Trichoderma koningiopsis* Th003. Mexican Journal of
540 Phytopathology 41(3): 412-433. <https://doi.org/10.18781/R.MEX.FIT.2305-1>
541

542 Zapata-Narváez YA, Díaz-García A, Beltrán-Acosta CR (2023) Alternatives for the gray
543 mold (*Botrytis cinerea*) control in cape gooseberry (*Physalis peruviana*) crop. Mexican
544 Journal of Phytopathology 41(3). <https://doi.org/10.18781/R.MEX.FIT.2302-5>
545

546 Zhang H, Kong N, Liu B, Yang Y, Li C, Qi J, Ma Y, Ji S, Liu Z (2022) Biocontrol potential
547 of *Trichoderma harzianum* CGMCC20739 (Tha739) against postharvest bitter rot of
548 apples. *Microbiological research*. 265, 127182.
549 <https://doi.org/10.1016/j.micres.2022.127182>