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Research Article

Evaluation of Control Methods for *Acusta tourannensis* (Souleyet,1842) (Gastropoda: Camaenidae) Infesting Dragon Fruit (*Selenicereus* spp.) in Vietnam

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ABSTRACT

Dragon fruit (*Selenicereus* spp.) cultivation in Vietnam faces severe losses due to *Acusta tourannensis* infestations, impacting yield and fruit quality. This study evaluated the efficacy of various control methods through field and greenhouse experiments in Binh Thuan Province, Vietnam, in 2023. Cultural practices, including reduced irrigation, herbicide application, and grass cutting, effectively suppressed snail populations by creating unfavorable conditions. Mechanical and manual removal methods, although useful, were labor-intensive. Bait trapping with dragon fruit parts was highly effective in capturing snails. Biological control using duck release significantly reduced snail densities, though contamination risks remain a concern. Botanical control with Saponin HF achieved mortality rates of 86.7–96.7% within 7–14 days. Chemical control with metaldehyde and niclosamide provided up to 100% mortality but necessitates careful management due to environmental risks. Integrated pest management (IPM) combining cultural, biological, and botanical control methods offers the most sustainable approach for managing *A. tourannensis* in dragon fruit orchards. Further research should focus on optimizing application rates and timing, developing eco-friendly alternatives such as plant-derived molluscicides, and assessing the long-term ecological impacts of these strategies. Enhancing these approaches will contribute to the effective and sustainable management of *A. tourannensis*, ensuring the viability of dragon fruit cultivation in Vietnam.

Key words: *Acusta tourannensis*, dragon fruit, integrated pest management, mollusk control, *Selenicereus* spp., terrestrial snails

INTRODUCTION

Dragon fruit (*Selenicereus* spp.) has emerged as a significant horticultural crop in Vietnam, contributing substantially to the national economy, particularly through exports. Major production regions include Binh Thuan, Long An, and Tien Giang (Hoat *et al*., 2018; Hien, 2019; Luu *et al*., 2021). Despite its economic importance, the dragon fruit industry faces significant challenges from terrestrial mollusks, particularly the snail *Acusta tourannensis*. These pests can cause substantial yield and quality losses, leading to significant economic impacts on farmers. While previous studies have investigated the diversity of terrestrial mollusks associated with dragon fruit cultivation in Vietnam (Hien *et al*., 2024), research specifically focusing on the biology, ecology, and effective control of *A. tourannensis* in these orchards remains limited (Binh Thuan Provincial Statistics Office, 2021).

Acusta tourannensis is a terrestrial mollusk belonging to the family Camaenidae. While its exact distribution within Vietnam is still being investigated, it has been recorded in various regions, including Pu Mat National Park, Lan Chau, and Hon Ngu islands of Cua Lo, Nghe An province (Do *et al*., 2022). This species is commonly found in anthropogenic habitats, such as wastelands and orchards, and its population densities can fluctuate significantly, posing a threat to crops (Nguyen & Do, 2022; Do *et al*., 2022).

Acusta tourannensis exhibits nocturnal activity and a strong preference for moist environments. Field observations have revealed seasonal peaks in *A. tourannensis* populations on dragon fruit branches and fruits, coinciding with periods of high rainfall and humidity. Our preliminary findings indicate that *A. tourannensis* exhibits temperature-sensitive reproductive behavior and that soil moisture significantly impacts its population dynamics and the extent of damage to dragon fruit plants (unpublished data). *A. tourannensis* can cause significant damage to dragon fruit plants by feeding on various plant parts, including leaves, stems, flowers, and fruits. This feeding activity can result in reduced plant growth, flower abortion, fruit damage, and, significant yield losses. The economic impact of *A. tourannensis* infestations on dragon fruit farmers can be substantial, affecting both production costs and market prices.

While mollusks play vital roles in soil ecology, contributing to nutrient cycling and soil aeration, uncontrolled populations, such as those of *A. tourannensis*, can cause significant damage to crops and disrupt ecosystem balance. Therefore, this study

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emphasizes the importance of integrated pest management (IPM) approaches in managing *A. tourannensis* populations in dragon fruit orchards. IPM strategies aim to combine multiple control methods, including cultural practices, mechanical and manual methods, bait trapping, and the application of biological, botanical, and chemical agents while minimizing environmental impacts to ensure sustainable and effective pest control.

MATERIALS AND METHODS

A series of field and greenhouse experiments were conducted in Phu Nhang village, Ham Hiep commune, Ham Thuan Bac district, Binh Thuan province, Vietnam, in 2023 to evaluate the effectiveness of various management strategies against *A. tourannensis* (Figure 1).

About 10-12-year-old dragon fruit gardens were selected for the experiments. According to TCVN 13268-4 (2021), the method for investigating snail density is as follows: Surveys were conducted in fixed dragon fruit gardens every 10 days. In each garden, 10 surveying points were selected, and at each point, one plant was investigated, counting the number of snails on 10 branches of the dragon fruit (including both the branches and the fruits). The investigation was conducted on the ground, around the base (dragon fruit stake), using a 0.2 m^2 quadrat frame. The number of snails was counted within the frame, and then the count was to snails per square meter.

Field experiments to evaluate the efficacy of pesticides are conducted according to TCVN 12561 (2022). For narrow-plot experiments, each plot has an area of 200 m^2 without replication. For large-scale experiments, each treatment has an area of 500 m^2 without replication. The experimental plots are arranged with a single row of dragon fruit plants. Five investigation points were selected along the diagonal for narrow-plot experiments and ten sampling points for large-scale experiments. The investigation points are similar to those used in the snail density investigation method.

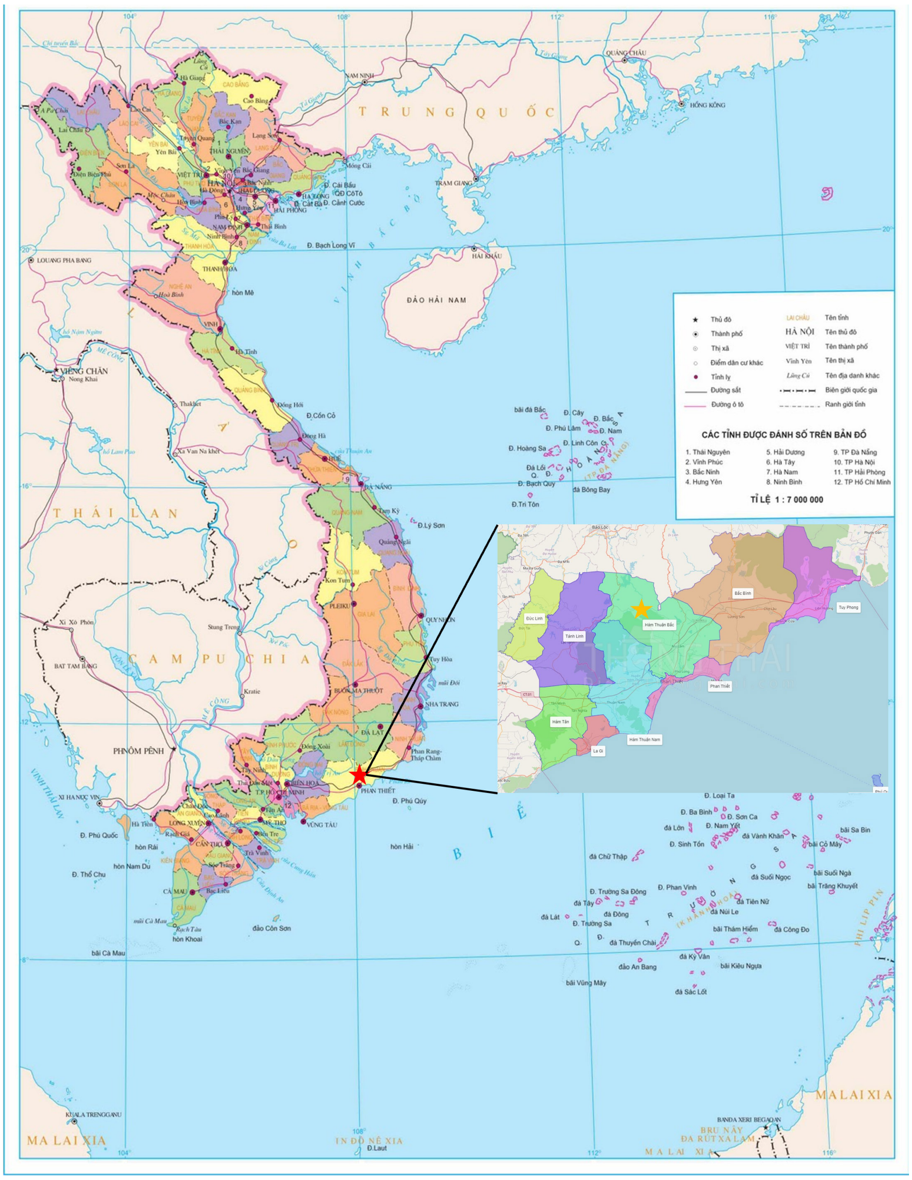

Fig. 1. Study map. Binh Thuan province is shown by a red star, and Ham Thuan Bac district is shown by a brown star

Evaluation of field sanitation measures on *A. tourannensis*

This experiment aimed to evaluate the effectiveness of the current methods being applied by farmers in the local area to control snail populations and minimize direct damage to dragon fruit products.

A field experiment was designed to assess the impact of different weed control methods applied by local farmers on *A. tourannensis* populations in dragon fruit orchards. Three treatments were implemented on a large scale without replication: Herbicide spraying with glufosinate ammonium (T1); Manual grass cutting (T2), and a combined herbicide spraying and manual grass cutting (T3).

Snail density on branches, fruits, and the soil surface was monitored ten times throughout the rainy season, both before and after the application of weed control measures, using standardized sampling techniques. Snail density was calculated using the following formulas:

Snail density (per branch, per fruit) = Total number of snails investigated / Total number of branches/fruits investigated.
Snail density on soil (per m^2) = Total number of snails in a 0.2 m^2 frame × 5.

Evaluation of irrigation practices on *A. tourannensis* populations

This field experiment evaluated the impact of different irrigation methods on *A. tourannensis* populations. Three irrigation treatments were implemented: Basin irrigation (T1); Basin irrigation combined with overhead tree irrigation (T2), and basin irrigation combined with both overhead tree and ground irrigation (T3). Basin irrigation involves directly watering the plant base using a flexible hose. Overhead tree irrigation utilized a fixed underground pipe system installed 30 to 40 cm deep along the dragon fruit rows. Every 6 meters, a pipe runs parallel to the rows, divided into sections with sprinklers spaced 9 meters apart. Each dragon fruit tree was equipped with an automatic rotating sprinkler positioned 2.0 to 2.5 meters above the ground. Ground irrigation employed a similar underground pipe system but with small pipes coiled around the dragon fruit trunks and equipped with sprinklers aimed at the soil.

Snail density on branches, fruits, and the soil surface was monitored ten times throughout the rainy season, both before and after the application of irrigation treatments. Data collection and analysis followed the methods described previously.

Evaluation of manual and mechanical control methods for *A. tourannensis*

This field experiment evaluated the effectiveness of various manual and mechanical control methods. Six treatments were implemented: Applying lime to trunks and stems (T1); Installing plastic barriers around the garden (T2); Placing packaging materials at the base of plants to trap snails (T3); Using dragon fruit branches and flowers as bait to attract and collect snails (T4); Spreading crushed eggshells around the trunks (T5), and a control group where farmers used chemical pesticides after rain (T6). Snail density was monitored ten times throughout the rainy season before and after applying control measures. Data collection and analysis followed the methods described previously.

Evaluation of bait trap attractiveness for *A. tourannensis*

Three independent field trials were conducted under mesh cage conditions to evaluate the attractiveness of different bait traps for *A. tourannensis*.

Experiment 1: Evaluating the attractiveness of dragon fruit plant parts to A. tourannensis

This experiment assessed the attractiveness of different dragon fruit plant parts to *A. tourannensis*. The experimental area was cleared of weeds, tilled, and enclosed with 100 cm^2 mesh cages with the edges buried 5 cm deep in the soil. Each cage contained 30 adult snails and one of four bait types: Fresh dragon fruit (undamaged and disease-free) (T1); Young dragon fruit branches freshly cut (T2); Soaked dragon fruit flowers (collected from the field, dried, and soaked in water for 15 min before use) (T3), and Rice bran water paste (T4). Baits were placed at the four corners of the cage and rotated between replicates, maintaining a distance of 70 cm between treatments and 15 cm from the cage mesh. Snail behavior and attraction to the baits were monitored daily for seven days between 18:00 and 20:00. The experiment was conducted from May 10 to May 17, 2023, with an average temperature ranging from 27.8ºC to 36.6ºC and air humidity at 72%. No rain occurred during the experiment period. The number of snails on each bait (individuals/bait/day) was recorded daily, and the snails were then returned to the center of the cage for continued monitoring.

Experiment 2: Evaluating the effectiveness of commonly used bait traps against A. tourannensis

This experiment assessed the effectiveness of commonly used bait traps in controlling *A. tourannensis*. Three bait types were evaluated at 10 points along diagonal lines in a dragon fruit orchard: Chicken feed mixed with water and Tatoo 150AB pesticide (T1); Rice bran mixed with water and Tatoo 150AB pesticide (T2), and young dragon fruit branches dipped in Sieu oc 4.0 pesticide solution (T3). Each bait was placed 50 cm from the trunk of a dragon fruit plant, and each replicate contained 30 adult snails. The number of snails attracted to each bait trap was monitored daily for six days.

Experiment 3: Optimizing bait trap placement for A. tourannensis control

This field experiment aimed to determine the optimal spacing for bait traps to control *A. tourannensis* populations within a dragon fruit orchard. Biological bait traps, consisting of dragon fruit flowers and branches, were placed in 1 m² piles between four dragon fruit trunks and sprayed with Sieu oc 4.0 pesticide. Six treatments were replicated three times: Traps placed 3 m apart (T1); Traps placed 10 m apart (T2); Traps placed 30 m apart (T3); Traps placed 50 m apart (T4); Traps placed 100 m apart (T5), and a control treatment (no traps) (T6). Snail density was monitored before trap placement (BTP) and 3, 7, 14, and 21 days after trap placement (DATP). The effectiveness of snail control (%) was assessed based on the reduction in snail density over time.

Efficacy of duck release as a biological control agent for *A. tourannensis* under large-scale field conditions

A field experiment was conducted from January to December 2023 to evaluate the effectiveness of duck release as a biological control method for *A. tourannensis* populations in dragon fruit orchards. Twenty domestic ducks (*Anas platyrhynchos domesticus*), also known as Chinese ducks, a common breed in Vietnam, were released per 1,000 square meters in the treatment group (T1). A control group received no duck release (T2). Snail density (number of snails per square meter) was monitored monthly throughout the year to assess the impact of duck predation on snail populations.

Efficacy of biological pesticides against *A. tourannensis* under greenhouse conditions

A greenhouse experiment was conducted from October to November 2023 to evaluate the efficacy of various biological pesticides against *A. tourannensis*. The experiment utilized large pots (diameter > 25 cm, bottom diameter of 17 cm, height 20 cm) filled with 5 cm clean, chemical-free soil. The soil surface was 7 cm below the pot's rim, and the soil was gently pressed down to compact it and prevent snail burrowing. Thirty adult snails with 4-5 whorls were introduced into each pot, along with three young dragon fruit branches (5 cm long) as a food source. The pots were then covered with insect-proof mesh.

After a 24-hr acclimatization period, the pesticide treatments were applied. Thirty min before pesticide application, the snails were lightly misted with clean water to encourage activity. Following pesticide application, the pots were sprayed with water once daily at 17:00 until the end of the experiment.

Eight treatments, each replicated three times, were evaluated: Dibonin super 15WP (3 g/pot) - a commercial product from Thailand (T1); Oc tieu 15 GR (3 g/pot) (T2); Sitto-nin 15BR (3 g/pot) – a commercial product in powder form (T3); Saponin HF solution (10% concentration) – an experimental, non-commercial solution (T4); Lime water (prepared by mixing 0.2 kg quicklime in 3 liters of water and allowing to settle for 24 hr before using the clear supernatant (T5); 0.9% saline solution (sprayed directly on snails) (T6); Crushed eggshells (crushed into sharp pieces and spread over the soil surface) (T7), and a control (sprayed with plain water) (T8).

Powdered pesticides were sprinkled onto the soil surface, while liquid and solution pesticides were sprayed directly onto the snails.

Snail mortality was monitored 1, 7, and 14 days after treatment. The efficacy of each treatment was calculated using the Abbott formula:

$$E\ (\%) = (1 - Ta)/Ca \times 100$$

Where E is the efficacy of the pesticide (%), and Ca and Ta are the densities of living *A. tourannensis* in the experimental conditions after and before treatment, respectively.

Efficacy of chemical pesticides against *A. tourannensis* under greenhouse conditions

A greenhouse experiment was conducted to evaluate the efficacy of various chemical pesticides against *A. tourannensis*. The experimental methodology mirrored that of the biological pesticide experiments.

The following treatments were evaluated: Abamectin (Aba-navi 4.0EC), 250 mL of pesticide per hectare (T1); Abamectin 40% (Hifi 3.6EC), 150 mL of pesticide per hectare(T2); Metaldehyde (Helix 500WP), 1.2 kg of pesticide per hectare/ha (T3); Metaldehyde (Tatoo 150AB), 5.0 kg of pesticide per hectare (T4); Metaldehyde + Niclosamide-olamine (Npio Dan 800WP), 0.5 kg of pesticide per hectare (T5); Metaldehyde + Niclosamide (Vit do 705WP), 0.6 kg of pesticide per hectare (T6), and a control (sprayed with plain water) (T7).

For liquid pesticides (T1, T2, T5, T6), 0.5 mL of Abamectin (T1), 0.6 mL of Abamectin 40% (T2), 1.3 mL of Metaldehyde + Niclosamide-olamine (T5), and 2.8 mL of Metaldehyde + Niclosamide (T6) were mixed with 1 liter of water, respectively. These solutions were then applied using a 2-litre hand sprayer to evenly wet the surface of the pot and the snails. For Metaldehyde (Tatoo 150AB) (T4), 0.5 grams of pesticide were mixed with 995 grams of dry soil. This mixture was then thoroughly blended and 7.25 grams of the mixture were applied evenly to the surface of the pot and snails. For all liquid pesticide treatments, any remaining pesticide solution was disposed of safely.

Powdered pesticides were sprinkled onto the surface of the soil. Snail mortality was monitored 1, 3, 7, and 14 days after treatment. The efficacy of each treatment was calculated using the Abbott formula:

$$E\ (\%) = (1 - Ta)/Ca \times 100$$

Where E is the efficacy of the pesticide (%), and Ca and Ta are the densities of living *A. tourannensis* in the experimental conditions after and before treatment, respectively.

Statistical analysis

Data collected from the field and greenhouse experiments were analyzed using Statistical Analysis System (SAS) software version 9.4. Analysis of Variance (ANOVA) was employed to determine significant differences between treatment means. Tukey's Honestly Significant Difference (HSD) test was used for pairwise comparisons. Regression analysis was conducted to assess the impact of dragon fruit variety and ecological factors on snail density. Data are presented as means ± standard error (SE). Statistical significance was set at a *P*-value of 0.05.

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RESULTS AND DISCUSSION

Evaluation of field sanitation measures on *A. tourannensis*

Field sanitation measures significantly impacted *A. tourannensis* density (Figures 2, 3 & 4). Grass cutting alone resulted in the highest snail densities across soil, branches, and fruit, peaking in mid-April and late September, suggesting this practice may create favorable conditions for snails. Herbicide spraying offered better control, leading to lower densities than grass cutting. However, the combined treatment of herbicide spraying and grass cutting consistently maintained the lowest and most stable snail densities across all measured areas (soil, branches & fruit) throughout the 2023 survey period. This synergistic effect likely results from a combination of reduced food sources, habitat disruption, and potential direct impacts on the snails. While herbicide spraying provides some level of control, it is most effective when implemented in conjunction with grass-cutting. These findings emphasize the importance of effective field sanitation in *A. tourannensis* management. Regular monitoring, manual removal, and habitat modification, such as clearing potential shelter sites, can further reduce snail populations and limit reliance on chemical controls. The combined herbicide spraying and grass-cutting approach offers the most promising strategy for significantly reducing snail densities on both ground and plant surfaces, minimizing crop damage. Further research is needed to fully elucidate the mechanisms by which these treatments influence snail populations, including the specific herbicides used, application timing, and the influence of environmental factors.

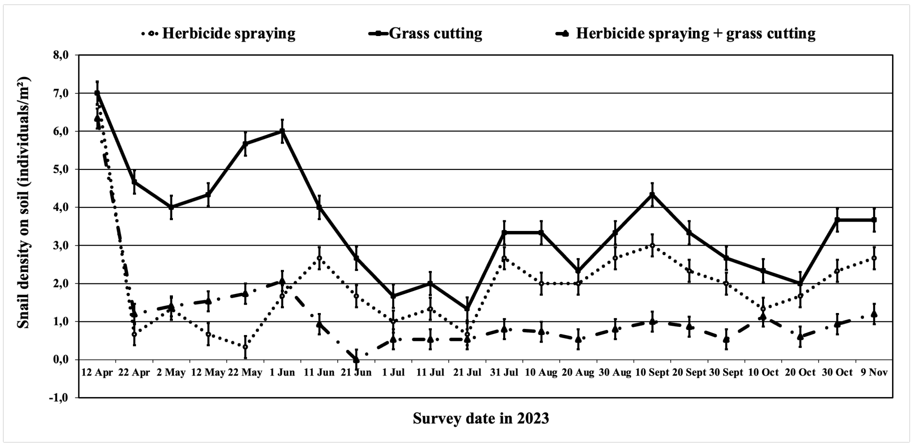

Fig. 2. Impact of different field sanitation measures on *A. tourannensis* density on planting soil

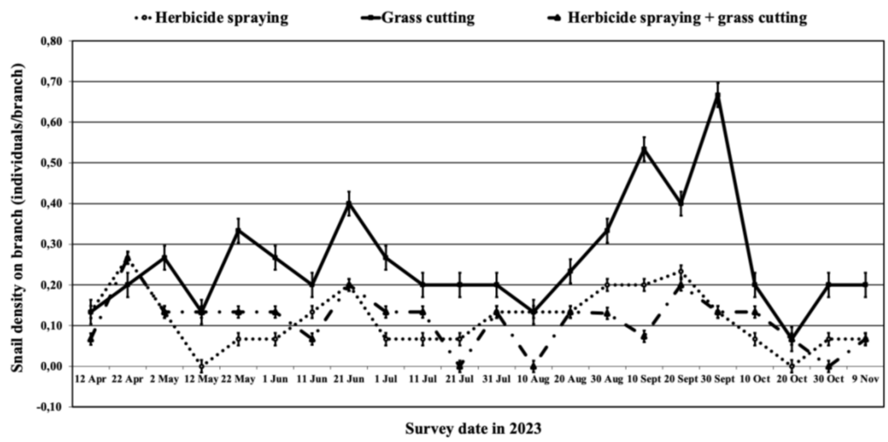

Fig. 3. Density of *A. tourannensis* (individuals/branch) on branches under different field sanitation measures in 2023

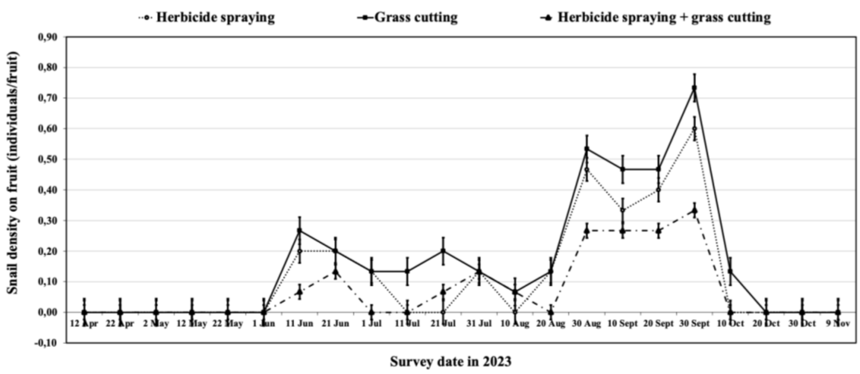

Fig. 4. Effect of field sanitation measures (herbicide spraying, grass cutting, and their combination) on *A. tourannensis* density (individuals/fruit) across survey dates in 2023

Evaluation of irrigation practices on *A. tourannensis* populations

Different irrigation methods significantly influenced *A. tourannensis* density across soil, branches, and fruit (Figures 5, 6 & 7). Basin irrigation consistently resulted in the highest snail densities in all three locations. Adding overhead tree irrigation to basin irrigation reduced snail numbers, suggesting a less favorable environment, possibly due to moisture dispersal or temperature fluctuations. The most substantial reduction was observed when ground irrigation was combined with both basin and overhead irrigation. This three-method approach consistently maintained the lowest snail populations, indicating a synergistic effect where the combined irrigation methods create the least hospitable conditions for *A. tourannensis*. These results suggest that while basin irrigation alone may promote higher snail populations, incorporating overhead irrigation offers some control, and adding ground irrigation provides the most effective means of suppression. This pattern was observed across soil, branches, and fruit, with the combined irrigation method consistently yielding the lowest snail densities. Further investigation is warranted to explore the specific mechanisms by which these irrigation methods influence snail ecology and population dynamics, as well as the suitability of fruits as a habitat. In conclusion, integrating basin, overhead, and ground irrigation significantly reduces *A. tourannensis* populations compared to basin irrigation alone. However, for enhanced sustainable control, incorporating water-saving techniques like drip irrigation and adjusting practices during the rainy season are crucial for minimizing soil moisture and further hindering snail proliferation.

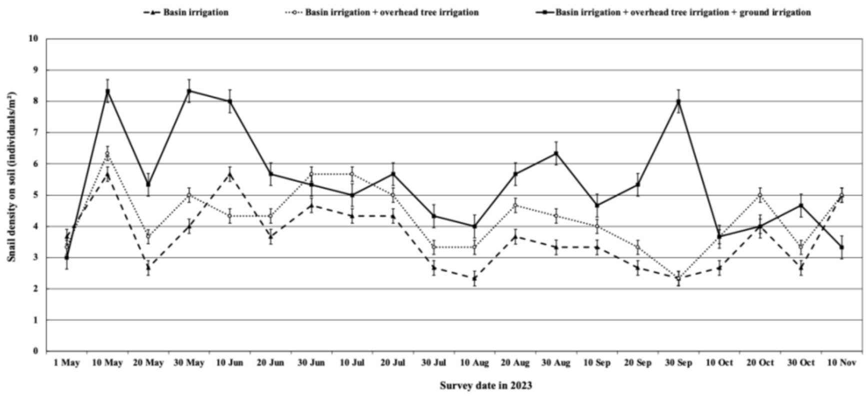

Fig. 5. Influence of basin irrigation, combined basin and overhead tree irrigation, and combined basin, overhead tree, and ground irrigation on *A. tourannensis* density (individuals/m^2) in planting soil

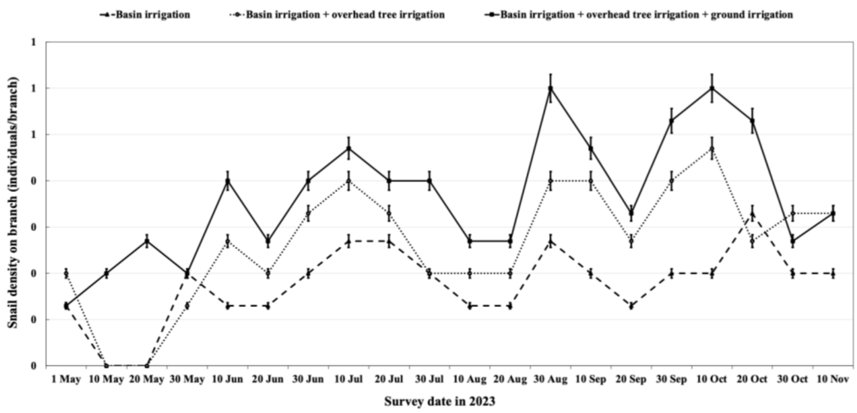

Fig. 6. Impact of different irrigation methods on *A. tourannensis* density on branches

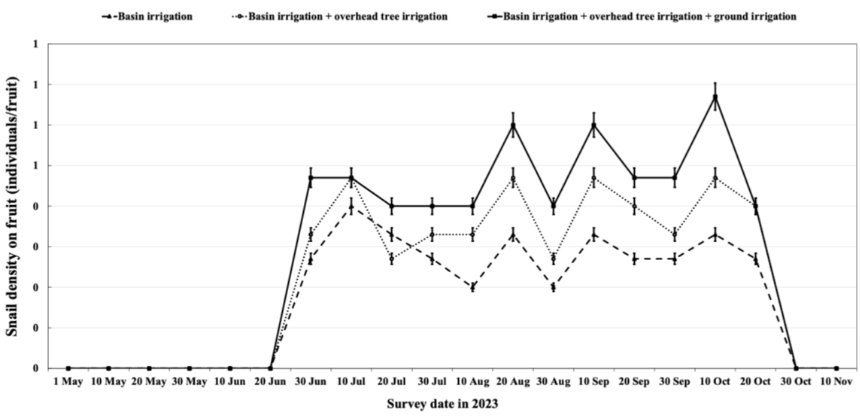

Fig. 7. Impact of different irrigation methods on *A. tourannensis* density on fruits

Evaluation of manual and mechanical control methods for *A. tourannensis*

Manual and mechanical control methods offer some potential for *A. tourannensis* management, particularly in small-scale infestations, though their effectiveness diminishes with larger infestations. Of the methods evaluated, removing and piling plant debris proved most effective, reducing snail densities to 1.1 individuals/m^2 and achieving 40.6% to 68.0% control compared to the control group. Eggshells and bait traps were less effective. Snail damage on branches and fruit peaked in August and October. Branch damage ranged from 0.13 to 0.33 individuals/branch, with the plant debris removal treatment (Treatment 2) showing the lowest density and the highest control. Fruit damage was most severe on 20 September 2023, with Treatment 3 consistently showing the lowest levels of damage on both branches and fruit (Figure 8). A combination of methods is crucial for effective control, as isolated methods, especially chemical pesticides, are often insufficient and can even lead to outbreaks. Bait traps using plant residues, for example, initially captured an average of 8.00 juvenile and 2.92 adult snails per trap per day, decreasing to 3.58 juveniles and 1.07 adults after 13 days.

While chemical treatments have limitations and alternative strategies like bait traps and repeated pesticide applications have limited efficacy (Hamir, 2010), traditional mechanical methods like handpicking and squashing offer a more sustainable, though labor-intensive, approach (Mahrous *et al*., 2002). Night-time collection when snails are more active, can be particularly effective (Hamir, 2010).

Future research should explore combining multiple control methods, such as manual removal, bait traps, and biological control, and investigate the impact of cultural practices like crop rotation and intercropping for sustainable management. Further investigation into the economic viability and long-term sustainability of these integrated approaches is also needed.

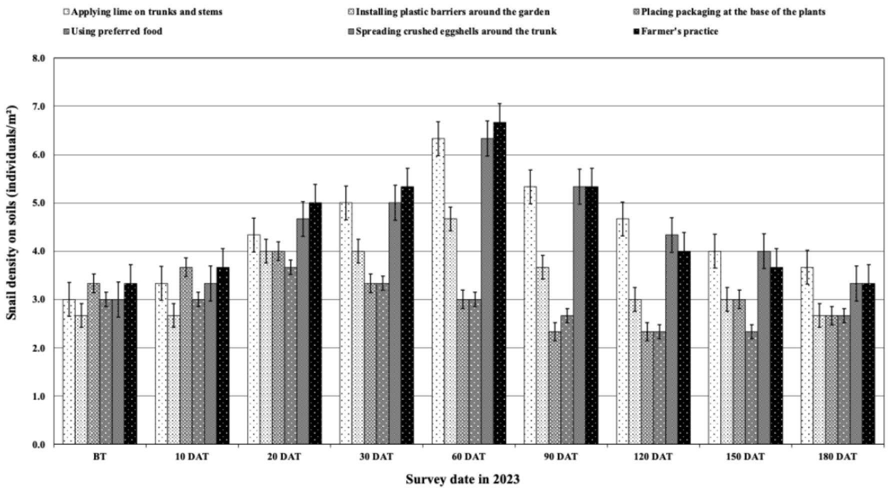

Fig. 8. Effectiveness of different manual and mechanical control measures against *A. tourannensis*

Evaluation of bait trap attractiveness for *A. tourannensis*

Experiment 1: Evaluating the attractiveness of dragon fruit plant parts to A. tourannensis

Biological and herbal control methods provide sustainable and environmentally friendly alternatives to chemical pesticides. This study evaluated the attractiveness of various food sources to *A. tourannensis* in a field setting, comparing fresh dragon fruit, young dragon fruit branches, dried dragon fruit flowers, and rice bran as bait. Results showed significant differences in attractiveness (Table 1). Dragon fruit-based baits were more effective than rice bran, attracting an average of 3.5 to 3.7 snails per bait per day compared to only 0.9 snails for rice bran. This indicates that baits using dragon fruit plant parts are significantly more attractive to *A. tourannensis*. While these findings strongly suggest the effectiveness of dragon fruit-based baits, it is important to acknowledge that environmental factors like temperature, humidity, and snail population density can influence snail attraction. Furthermore, variations in bait preparation, such as soaking dried flowers in water before use to potentially enhance attractiveness, suggest that moisture content may play a role in bait design and efficacy.

Table 1. Attractiveness effectiveness of different types of food to *A. tourannensis* on dragon fruit in Binh Thuan, 2023

Treatment	Number of snails attracted to different types of food on days after treatment (snails/food/day)					
	3 DAT	5 DAT	7 DAT	Average	Highest	Lowest
Treatment 1	5.3^b	3.3^b	2.0^{ab}	3.7^a	6.3	0.7
Treatment 2	8.0^a	5.3^a	2.7^{ab}	3.5^a	8.0	0.0
Treatment 3	6.3^b	2.3^{bc}	3.3^a	3.6^a	6.3	0.3
Treatment 4	0.7^c	1.7^c	0.0^b	0.9^b	1.7	0.0
CV (%)	*13.5*	*20.4*	*68.7*	*13.3*	-	-
$LSD_{0.05}$	*1.37*	*1.29*	*2.75*	*0.77*	-	-

Note: Treatment 1: Dragon fruit (freshly cut, undamaged & disease-free). Treatment 2: Young dragon fruit branch (freshly cut). Treatment 3: Dragon fruit flower (collected from the field, dried, and soaked in water for 15 min before use). Treatment 4: Rice bran (mixed with water to form a paste). The mean followed by the same letter in the same column is not significantly different at *P*<0.05 using Tukey's HSD test.

Experiment 2: Evaluating the effectiveness of commonly used bait traps against A. tourannensis.

This experiment evaluated the effectiveness of different bait types in traps against *A. tourannensis* (Table 2). Young dragon fruit branches proved the most effective bait, capturing an average of 3.4 snails per trap per day. Chicken feed was the second most effective, attracting 2.2 snails per trap per day, while rice bran was the least effective, attracting only 1.9. Young dragon fruit branches, particularly when treated with pesticides, offer a promising tool for *A. tourannensis* control. Given the importance of diet for snail growth, reproduction, and survival, and the known preference of *A. tourannensis* for chicken feed and dragon fruit, these results are not surprising. However, bait trap efficacy is influenced by environmental conditions, snail population density, and bait formulation. Further research is needed to optimize bait trap design, placement, and preparation. Integrated pest management (IPM) strategies are crucial. Bait traps can be particularly effective during the early rainy season, reducing populations by 55-75% (Mahrous *et al*., 2002) due to increased snail susceptibility in wet conditions. Similarly, placing bags of attractants like chicken feed at the base of plants can reduce infestations by 50.8-68.0% (Hamir, 2010), exploiting the snails' preference for readily available food.

Table 2. Effectiveness of commonly used bait traps by farmers to control *A. tourannensis*

Treatment	Density of snails on different days after treatment (snails/bait trap/day)						
	1 DAT	2 DAT	3 DAT	4 DAT	5 DAT	6 DAT	Average
Treatment 1	2.3	5.2	3.3	1.6	0.4	0.4	2.2
Treatment 2	2.7	1.5	2.2	3.1	0.7	1.1	1.9
Treatment 3	3.4	3.0	4.9	3.5	2.7	2.9	3.4

Note: Treatment 1: Chicken feed (mixed with water to form a sticky paste and combined with Tatoo 150AB pesticide). Treatment 2: Rice bran (mixed with water to form a sticky paste and combined with Tatoo 150AB pesticide). Treatment 3: Young dragon fruit branch (cut from the plant and dipped in Sieu oc 4.0 pesticide solution).

The appropriate distance for placing bait traps to control *A. tourannensis*

Optimizing bait trap effectiveness is crucial for *A. tourannensis* control. An experiment evaluated trap spacing (3, 10, 30, 50 & 100 m) to determine optimal placement. Initial snail densities ranged from 14.7 to 17.0 individuals/m^2, with the untreated control reaching 21.0 individuals/m^2 by day 21 (Table 3). Traps placed 3m apart achieved the highest efficacy (74.6% reduction by day 21). A clear inverse relationship existed between trap spacing and control efficacy. Wider spacing significantly reduced effectiveness, with traps at 30, 50, and 100 m achieving only 19.1%, 8.6%, and 4.8% reductions, respectively. These results strongly indicate that bait traps should be placed 3-10 m apart for optimal *A. tourannensis* control in dragon fruit orchards. The reduced efficacy with wider spacing likely stems from decreased snail attraction over greater distances. Integrating bait traps with other control methods warrants further investigation for sustainable *A. tourannensis* management. These findings provide valuable guidance for farmers, supporting the recommendation for closer trap spacing, especially in heavily infested areas, to enhance control and minimize economic losses.

Table 3. Effectiveness of different trap placement distances in attracting *A. tourannensis*

Treatment	Efficacy (%)			
	3 DAT	7 DAT	14 DAT	21 DAT
Treatment 1	56.6	60.6	63.7	74.6
Treatment 2	29.8	35.5	45.1	53.6
Treatment 3	9.6	16.3	15.8	19.1
Treatment 4	1.5	3.0	4.6	8.6
Treatment 5	1.4	2.8	4.3	4.8
Treatment 6 (Control)	-	-	-	-

Note: Treatment 1: Traps placed 3 m apart; Treatment 2: traps placed 10 m apart; Treatment 3: traps placed 30 m apart; Treatment 4: traps placed 50 m apart; Treatment 5: traps placed 100 m apart; Treatment 6 (Control): no traps placed.

Efficacy of duck release as a biological control agent for *A. tourannensis* under large-scale field conditions

Ducks effectively control *A. tourannensis* in dragon fruit orchards. Control group snail densities peaked at 6.67 individuals/m^2 in June and 3.67 individuals/m^2 in September, significantly higher than the duck-released group's peaks of 2.33 individuals/m^2 (June) and 2.00 individuals/m^2 (October) (Figure 9). This demonstrates the ducks' ability to suppress snail populations. As natural predators, ducks offer a valuable method for reducing snail numbers and crop damage, consistent with previous research on poultry as snail control (Gabr *et al*., 2006). While factors like duck density, habitat, and alternative food sources can influence effectiveness, the study reveals a clear trend. Both groups experienced initial population increases with warmer temperatures, peaking around May/June. However, the duck-released group consistently maintained lower densities, especially after April. The largest density difference coincided with the control group's peak growth, highlighting the ducks' impact during periods of rapid snail proliferation. Despite some fluctuations and potentially limited statistical significance at certain points due to overlapping error bars, the overall trend strongly supports using ducks for *A. tourannensis* control. Further research is recommended to optimize duck deployment, focusing on stocking densities, breed selection, and environmental influences.

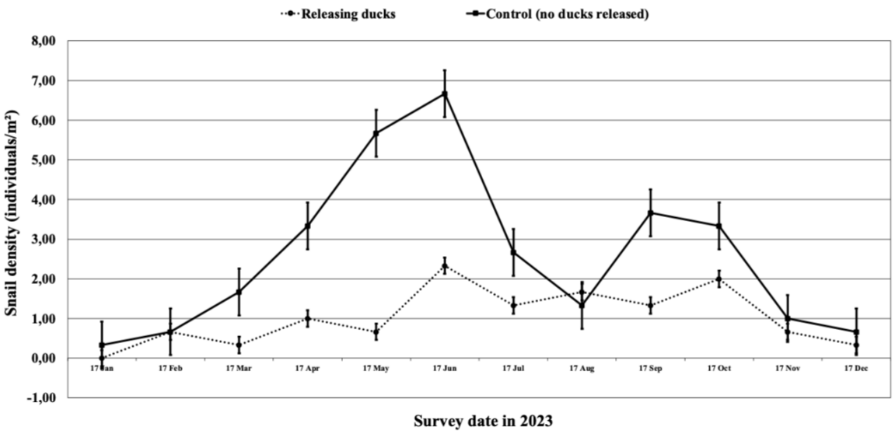

Fig. 9. Field evaluation of duck release as a biological control agent for *A. tourannensis*: Impact on snail density

Efficacy of biological pesticides against *A. tourannensis* under greenhouse conditions

Greenhouse trial evaluated the efficacy of several biological pesticides against *A. tourannensis*. Commercially available saponin-based products provided moderate control, ranging from 33.3% to 66.7% at 14 days after treatment. However, an experimental Saponin HF solution demonstrated significantly higher efficacy, achieving 86.7% to 96.7% control between 7 and 14 days (Table 4). This supports previous research on the potential of botanical molluscicides for sustainable pest management (Shoieb, 2008). Sodium chloride, despite its dehydrating properties and reported use in snail eradication (Zala *et al*., 2018), proved ineffective in this trial. Likewise, lime water, saline solution, and crushed eggshells failed to control snail populations, consistent with earlier findings (El-Deeb *et al*., 2003). While botanical extracts like *Barringtonia racemosa* seed extract have shown promise against other snail species (e.g., *Pomacea canaliculata*), this was not investigated here. These results suggest that while commercial saponin products offer some *A. tourannensis* control, developing more effective and environmentally friendly biopesticides, like the experimental Saponin HF, is crucial for sustainable management. Further research should explore the long-term efficacy of Saponin HF under field conditions and assess its impact on non-target organisms to ensure its viability as a safe and sustainable control method.

Table 4. Efficacy of some biological pesticides against *A. tourannensis*

Treatment (active ingredient)	Dosage	Efficacy (%)		
		1 DAT	7 DAT	14 DAT
Dibonin super 15WP (saponin)	3 g/pot	40.0^{b}	46.7^{bc}	46.7^{c}
Oc tieu 15 GR (saponin)	3 g/pot	13.3^{c}	33.3^{c}	33.3^{d}
Sitto-nin 15BR (saponin)	3 g/pot	13.3^{c}	60.0^{b}	66.7^{b}
Saponin HF	1 lit/10 L. water	60.0^{a}	86.7^{a}	96.7^{a}
Lime	0.2 kg/3 L. water	0.0^{c}	0.0^{d}	0.0^{e}
Sodium Chloride 0.9%	0.9%	0.0^{c}	0.0^{d}	0.0^{e}
Eggshells	3 g/pot	0.0^{c}	0.0^{d}	3.3^{e}
Control (No Treatment)	Water	-	-	-
CV (%)		45.4	26.4	14.1
$LSD_{0.05}$		14.6	15.2	8.82

Note: The mean followed by the same letter in the same column is not significantly different at *P*<0.05 using Tukey's HSD test.

Efficacy of chemical pesticides against *A. tourannensis* under greenhouse conditions

A greenhouse trial evaluated the efficacy of several chemical pesticides against *A. tourannensis* (Table 5). Metaldehyde-based products, including Metaldehyde (Helix 500WP), and Metaldehyde (Tatoo 150AB) provided the most effective control, achieving 100% mortality by 14 days post-treatment. The combination of metaldehyde and niclosamide (Vịt đỏ 705WP) also achieved complete control at all observation points. Abamectin-based treatments (Aba-navi 4.0EC & Hifi 3.6EC) were less effective, with Aba-navi 4.0EC reaching a maximum 83.3% mortality and Hifi 3.6EC only 36.7% by 14 days. This difference in efficacy likely stems from their respective modes of action: metaldehyde causes excessive mucus secretion and dehydration (Henderson, 1970; Henderson & Triebskorn, 2002; Abd El-Wakeil, 2005), leading to rapid mortality, while abamectin targets the nervous system, resulting in slower kill rates. Metaldehyde, often applied as pellets to reduce disintegration, is a common and effective molluscicide (Zala *et al*., 2018), with its mechanism of action involving the stimulation of mucous glands, leading to dehydration and death (Henderson, 1970; Henderson & Triebskorn, 2002; Abd El-Wakeil, 2005). Other chemicals like abamectin (effective against *Eobania vermiculata* & other mollusks (Essawy *et al*., 2009; Abdallah *et al*., 2015; Hemmaid *et al*., 2017)), indoxacarb and fipronil (effective against adults & eggs (Shaker *et al*., 2015; Hussein & Sabry, 2019)), diethyldithiocarbamate (reduces egg hatchability (El-Bolkiny *et al*., 2000)), ferrous sulfate, urea, and calcium superphosphate (effective against various land snails (El-Massry *et al*., 1998)) have also shown molluscicidal properties. Other insecticides like methomyl, oxamyl, acetamiprid, and lambda-cyhalothrin have demonstrated effectiveness against *E. vermiculata* (Essawy *et al*., 2009; Abdallah *et al*., 2015; Hemmaid *et al*., 2017), though their environmental impact must be considered (Kumar, 2020). Niclosamide, is particularly effective against both eggs and adults of multiple snail species, and other compounds like nicotinanilide, thiamethoxam, and diafenthiuron also offer molluscicidal options (Kengne Fokam *et al*., 2022). Humid conditions often increase the toxicity of these compounds, aligning with optimal gastropod habitats (Bhavsar & Patel, 2011; Samy *et al*., 2015). Metaldehyde and metaldehyde + niclosamide are most effective when applied between 6:00 PM and 6:00 AM, or during cooler conditions, after watering or rain. Snail activity was most pronounced when soil moisture exceeded 80%. Innovative strategies, such as metaldehyde pellets affixed to cords, combine physical and chemical control (Pieterse *et al*., 2020).

Table 5. Efficacy of some chemical pesticides against *A. tourannensis*

Active ingredient (Commercial name)	Dosage	Efficacy (%)			
		1 DAT	3 DAT	7 DAT	14 DAT
Abamectin (Aba-navi 4.0EC)	250 mL/ha	3.3^{c}	43.3^{cd}	73.3^{bc}	83.3^{ab}
Abamectin (Hifi 3.6EC)	150 mL/ha	0.0^{c}	26.7^{d}	33.3^{d}	36.7^{c}
Metaldehyde (Helix 500WP)	1.2 kg/ha	6.7^{c}	56.7^{bcd}	86.7^{abc}	90.0^{a}
Metaldehyde (Tatoo 150AB)	5.0 kg/ha	6.7^{c}	76.7^{ab}	93.3^{ab}	100.0^{a}
Metaldehyde + niclosamide-olamine (Npiodan 800WP)	0.6 kg/ha	60.0^{b}	63.3^{bc}	66.7^{c}	66.7^{b}
Metaldehyde + niclosamide (Vit do 705WP)	0.5 kg/ha	100.0^{a}	100.0^{a}	100.0^{a}	100.0^{a}
Control (no Treatment)	Water	-	-	-	-
CV (%)		21.2	27.3	16.7	12.9
$LSD_{0.05}$		11.3	30.4	22.9	18.7

Note: The mean followed by the same letter in the same column is not significantly different at $P<0.05$ using Tukey's HSD test.

CONCLUSION

Dragon fruit (*Selenicereus* spp.) cultivation in Vietnam faces significant economic losses due to the damage inflicted by *A. tourannensis*, which directly affects the fruit and branches, reducing their marketability. Effective management of this terrestrial mollusk species requires an integrated approach due to its complex behavior and adaptability to environmental conditions. This study demonstrated that metaldehyde-based chemical control methods were the most effective, achieving up to 100% mortality under greenhouse conditions, though their use must be carefully managed to minimize environmental and health risks. Biological and cultural methods, such as saponin-based biopesticides, manual removal, bait trapping, and the use of plant debris, showed varying degrees of success, with duck release offering effective control despite contamination concerns. Irrigation and field sanitation practices significantly influenced snail populations, highlighting the need for proper water management to reduce infestation risks. This study underscores the importance of integrated pest management (IPM) for sustainable *A. tourannensis* control. Combining cultural, botanical, biological, and chemical strategies provides the most effective and environmentally responsible approach while reducing reliance on pesticides.

Future research should focus on developing eco-friendly alternatives, such as plant-derived molluscicides, and evaluating their long-term ecological impacts. Further optimization of bait trap design, manual removal techniques, biological control, and cultural practices like crop rotation is essential. Investigating the effectiveness of duck deployment and assessing the field efficacy of Saponin HF will enhance sustainable control methods. Advancing these strategies will contribute to the effective and long-term management of *A. tourannensis*, ensuring the sustainability of dragon fruit cultivation in Vietnam.

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ETHICAL STATEMENT

Not applicable.

CONFLICT OF INTEREST

The authors declared no conflict of interest.

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