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Research Article

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Pest Regulation and Natural Enemy Support in Agroforestry Systems: Evidence from *Grevillea robusta* with Tomato-Based Alley Cropping in Nyagatare District, Rwanda

Gaspard R. Ntabakirabose[1], Jean de Dieu Buregeya[2], Julienne Uwitonze[3], Festus Maniriho[4], Mbabazi Mbabazize[5], and Charles Halerimana[6]
[1]*Forest Research Department, Rwanda Forestry Authority, Huye, Rwanda*
[2]*Department of Transforming the Eastern Province through Adaptation to Climate Change, Rwanda Forestry Authority, Huye, Rwanda*
[3]*Environmental Economics and Natural Resources, Management; University of Lay Adventist of Kigali, Rwanda*
[4]*Forest Investment Program, Rwanda Forestry Authority, Huye, Rwanda*
[5]*Faculty of Business and Commerce, ISBAT University, Kampala, Uganda*
[6]*Department of Crop Science and Horticulture, Makerere University, Uganda*
**Corresponding author e-mail: gmutago@gmail.com*
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ABSTRACT
Tomato (*Solanum lycopersicum* L.) is an important vegetable crop in Rwanda, but its production is constrained by severe insect pest infestations and excessive pesticide use. This study evaluated the effectiveness of *Grevillea robusta*–tomato alley cropping in suppressing sap-sucking pests, enhancing natural enemy populations, and improving tomato productivity in Nyagatare District, Eastern Rwanda. A field experiment was conducted using a randomized complete block design with two treatments: alley cropping and sole tomato cropping. Pest and natural enemy populations were monitored throughout the cropping season, while growth, yield, and pest damage parameters were assessed. Results revealed that alley cropping reduced major sap-sucking pest populations by 53.7–57.8% compared with sole cropping. The abundance and diversity of natural enemies, including lady beetles, lacewings, spiders, and parasitoid wasps, increased significantly, leading to greater biological control activity. Consequently, marketable tomato yield increased by 29%, while pest damage declined by over 50%. The findings highlight alley cropping as a sustainable pest management strategy for smallholder tomato production in Rwanda.
Keywords: Pest, Natural enemy, Agroforestry, Tomato, Alley cropping

INTRODUCTION

Tomato (*Solanum lycopersicum* L.) is one of the most important vegetable crops in Rwanda, playing a key role in household nutrition, food security, and income generation for smallholder farmers. Its short production cycle and high market demand make it a preferred crop across many agroecological zones, including Nyagatare District in Eastern Rwanda (NAEB, 2024; PRIMO MEDIA Rwanda, 2025; World Bank & GoR,2025).

However, tomato production is highly vulnerable to insect pest infestations, particularly sap-sucking pests such as whiteflies (Bemisia tabaci), aphids (*Myzus persicae*, *Aphis gossypii*), thrips (*Frankliniella occidentalis*, *Thrips tabaci*), spider mites (*Tetranychus urticae*), and leafhoppers (*Empoasca* spp.) (Meys,2025; Kansas State University, 2025; Sadek,2025; Asiry et al, 2022). These pests cause direct feeding damage, reduce plant vigor, transmit viral diseases, and ultimately lead to substantial yield and quality losses (Dabalo,2024; Ghareeb & Al-Quraishy,2024; Asiry et al, 2022).

In recent years, pest pressure in tomato systems has intensified due to factors such as climate variability, expansion of intensive monocropping, and landscape simplification (Grab,2018; Majaliwa & Sekamatte, 2023). In Nyagatare District, tomato production is predominantly based on monoculture systems that offer limited ecological regulation of pest populations. As a result, farmers rely heavily on chemical pesticides as the primary pest management strategy (Ndisanze et al.,2022; MINAGRI, 2024). While pesticides may provide short-term control, their excessive use increases production costs, contributes to pest resistance, disrupts beneficial insect populations, and poses risks to human health and the environment (Daniel, 2024; Da Costa & Andrade, 2024; Ahmad et al, 2024).

The increasing prevalence of sap-sucking pests in tomato fields of Nyagatare District has resulted in significant yield losses and reduced profitability for smallholder farmers (Ndereyimana et al, 2019; RoR& World Bank, 2025). Intensive monocropping systems provide favorable conditions for rapid pest population buildup while limiting the presence and effectiveness of natural enemies such as predators and parasitoids (Landis et al., 2000; Bianchi et al., 2019). The continued dependence on chemical pesticides under these conditions is unsustainable and undermines long-term agricultural productivity and environmental health (Gulzar, 2025).

Agroforestry systems, particularly alley cropping with *Grevillea robusta*, offer a promising ecologically based alternative by increasing habitat complexity, moderating microclimatic conditions, and providing resources that support natural enemy populations (Jose, 2015; Muchiri,2022; Zhang & Zhang, 2023; Batáry et al, 2024). However, despite the widespread presence of *Grevillea robusta* in Rwandan farming systems, there is limited experimental evidence on its role in regulating sap-sucking pests and enhancing biological control in tomato production, especially under the specific agroecological conditions of Nyagatare District (Byiringiro & Kayijuka, 2024; Ruticumugambi et al.,2025). This lack of localized, empirical data constrains the adoption of agroforestry-based pest management strategies. Addressing this knowledge gap is critical to developing sustainable, low-input tomato production systems that reduce dependence on pesticides while improving crop productivity and resilience.

Understanding the interactions among cropping systems, pest populations, and natural enemies is essential for designing sustainable and productive tomato agroecosystems. Therefore, this study aimed to evaluate the role of *Grevillea robusta* alley cropping in regulating major sap-sucking pests, enhancing the diversity and abundance of natural enemies, and determining its effects on tomato growth, yield, and crop health under pest pressure in Nyagatare District, Rwanda. Specific objectives are to assess sap-sucking pest populations in tomato under *Grevillea robusta* alley cropping versus sole cropping, to evaluate the diversity and abundance of natural enemies and their role in pest suppression, and to determine the effects of alley cropping on tomato growth, yield, and crop health under pest pressure.

MATERIALS AND METHODS

Study area

The study was conducted in Nyagatare District, located in the Eastern Province of Rwanda. The district is characterized by a semi-arid climate with bimodal rainfall totalling approximately 800–900 mm per year and mean annual temperatures ranging between 20 and 25 °C. Soils in the area are predominantly Ferralsols, which are commonly used for both yearly crop production and agroforestry practices. Nyagatare District is well-suited for the integration of *Grevillea robusta* with tomato production and is known to experience frequent infestations of sap-sucking insect pests, including aphids, whiteflies, and thrips, making it an appropriate location for studying pest regulation and natural enemy dynamics in agroforestry systems.

Experimental design and treatments

The experiment was laid out using a Randomized Complete Block Design (RCBD) to account for spatial variability within the experimental field. Two cropping systems constituted the treatments: an alley cropping system in which tomato was grown between rows of *Grevillea robusta*, and a sole cropping system where tomato was grown without trees, serving as the control. Each treatment was replicated three to four times across blocks. Individual plots measured approximately 5 m × 5 m, although plot size was adjusted depending on field conditions. In the alley cropping system, *Grevillea robusta* trees were established at spacings of approximately 8–10 m between rows, while tomato plants in both systems were planted following standard agronomic recommendations, with 50 × 60 cm spacing. To allow natural interactions between pests and their natural enemies, no synthetic insecticides were applied throughout the duration of the experiment.

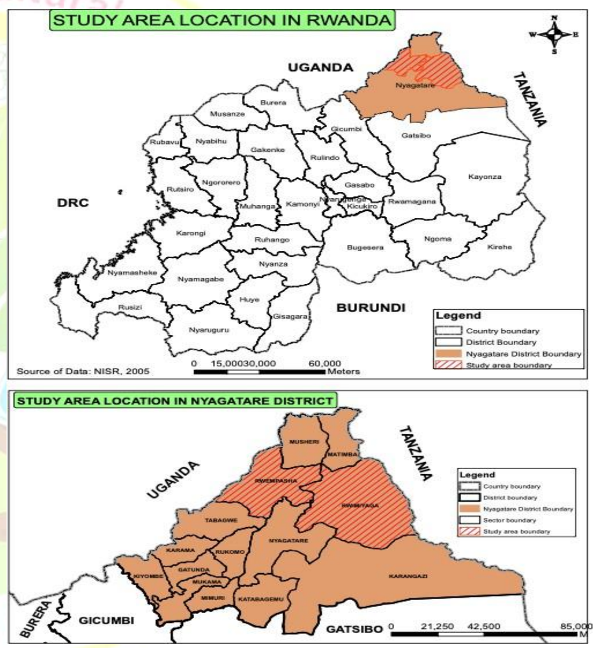

Figure 1. Maps of the study area and location

Crop and tree management

A tomato (Lycopersicon esculentum) variety commonly cultivated in Nyagatare District was used to ensure relevance to local farming systems. All experimental plots received uniform agronomic management practices, including land preparation, fertilization, irrigation, and weed control, to minimize management-related variability between treatments. Before tomato transplanting, *Grevillea robusta* trees in the alley cropping system were uniformly pruned to reduce excessive shading and to ensure comparable growing conditions across plots.

Data collection methods

Assessment of sap-sucking pest populations

Sap-sucking pest populations were assessed to address the first objective of the study. Target pests included aphids (*Myzus persicae*, *Aphis gossypii*), whiteflies (*Bemisia tabaci*), thrips (*Frankliniella occidentalis*, *Thrips tabaci*), spider mites (*Tetranychus urticae*), and leafhoppers (*Empoasca* spp.). Pest sampling was conducted bi-weekly, starting two weeks after transplanting and continuing until harvest. In each plot, five to ten tomato plants were randomly selected and permanently tagged for repeated observations. Pest counts were carried out on tree canopy strata (upper, middle, and lower leaves) of each sampled plant. Aphids and whiteflies were assessed through direct leaf counts, while thrips and spider mites were sampled by gently tapping foliage onto a white tray or through careful visual inspection. Leafhoppers were counted visually on leaves. Pest abundance was expressed as mean pest density per plant or per leaf.

Diversity and abundance of natural enemies

The diversity and abundance of natural enemies were evaluated to address the second objective of the study. Natural enemies observed included lady beetles, lacewings, spiders, parasitoid wasps, predatory bugs, and ants. Sampling was conducted concurrently with pest assessments. Natural enemies were recorded through direct visual observations on the same tomato plants used for pest counts, sweep net sampling along transects within each plot, and the deployment of yellow sticky traps placed at canopy height at a density of one to two traps per plot. Where necessary, pitfall traps were used to capture ground-dwelling predators. All sampling followed the same temporal frequency as pest assessments to allow comparison between pest and natural enemy dynamics.

Captured natural enemies were identified to family or genus level using standard taxonomic keys. Biodiversity metrics, including species richness, Shannon–Wiener diversity index (H′), and relative abundance, were calculated for each treatment. To assess the role of natural enemies in pest suppression, correlation and regression analyses were conducted between pest densities and natural enemy abundance, and predator pest ratios were used as indicators of biological control potential.

Tomato growth, yield, and crop health

Tomato growth, yield, and crop health parameters were measured to address the third objective of the study. Growth parameters, including plant height and number of branches, were measured on the same tagged plants used for pest and natural enemy assessments, while leaf area index was measured where resources allowed. Yield data were collected by recording the number of fruits per plant, average fruit weight, and both marketable and total yield expressed in tonnes per hectare. Crop health was evaluated through visual scoring of pest damage using a standardized scale (0–5), assessment of the incidence of pest-transmitted diseases such as viral infections, and determination of the percentage of damaged fruits at harvest.

Data analysis

Data on pest populations, natural enemy abundance, tomato growth, yield, and crop health were subjected to analysis of variance (ANOVA) to test for treatment effects. Mean separation was performed using Tukey's Honestly Significant Difference (HSD) test or Least Significant Difference (LSD) at a significance level of $p \leq 0.05$. Diversity indices were compared between alley cropping and sole cropping systems using appropriate statistical tests. Correlation and regression analyses were used to explore relationships among pest suppression, natural enemy activity, and tomato yield. All statistical analyses were conducted using SPSS. Biological control efficiency (BCE) was calculated using the formula:

$$\text{BCE (\%)} = \frac{Pest\ density\ in\ control - Pest\ density\ in\ treatment}{Pest\ density\ in\ control} x100$$

RESULTS AND DISCUSSION

An abundance of major sap-sucking pests on tomato under different cropping systems

Table 1 shows that the abundance of all major sap-sucking pests was consistently lower in the *Grevillea robusta*–tomato alley cropping system compared with the sole tomato cropping system. The results of the study showed that across pest species, reductions in pest populations under alley cropping ranged from 53.7% to 57.8%, indicating a strong suppressive effect of the agroforestry system on pest incidence.

The results of the study revealed that whitefly (Bemisia tabaci) populations were reduced by 54.5% in alley cropping compared to sole cropping. This substantial reduction suggests that the presence of *Grevillea robusta* alters the crop microclimate and disrupts the host-finding behavior of whiteflies, in addition to supporting natural enemies that regulate their populations.

However, the results indicated that aphid (*Aphis gossypii*) abundance was significantly lower in alley cropping, with a 57.8% reduction relative to sole tomato cropping. Aphids are highly responsive to habitat complexity, and their lower density under alley cropping may be attributed to increased predation and parasitism, as well as reduced suitability of the environment due to shading and plant diversity.

The results of the study revealed that thrips (*Thrips tabaci*) populations showed a 55.9% reduction under alley cropping. Thrips typically thrive in simplified cropping systems; therefore, the diversified structure created by *Grevillea robusta* likely interfered with their population build-up by limiting favorable conditions and enhancing biological control.

Similarly, spider mite (*Tetranychus urticae*) abundance was reduced by 57.1% in alley-cropped tomato. The moderated temperature and increased humidity associated with tree presence may have created less favorable conditions for mite proliferation, while also favoring predatory arthropods.

Whereas leafhopper (*Amrasca biguttula*) populations were the lowest among the recorded pests in both systems, yet still showed a 53.7% reduction under alley cropping. This indicates that even highly mobile pests are affected by increased habitat complexity and ecological interactions in agroforestry systems.

Overall, the results demonstrate that *Grevillea robusta*–based alley cropping effectively suppresses sap-sucking pest populations in tomato, likely through a combination of enhanced natural enemy activity, microclimatic modification, and disruption of pest colonization processes. These findings highlight the potential of agroforestry systems as a sustainable pest management strategy in tomato production

Table 1. Mean abundance of major sap-sucking pests on tomato under different cropping systems

Pest species	Grevillea + tomato (no./plant)	Sole tomato cropping (no./plant)	% Reduction under alley cropping
Whiteflies (Bemisia tabaci)	8.6 ± 1.2	18.9 ± 2.3	54.5
Aphids (*Aphis gossypii*)	6.2 ± 0.9	14.7 ± 1.8	57.8
Thrips (*Thrips tabaci*)	4.1 ± 0.6	9.3 ± 1.1	55.9
Spider mites (*Tetranychus urticae*)	5.4 ± 0.8	12.6 ± 1.5	57.1
Leafhoppers (*Amrasca biguttula*)	3.8 ± 0.5	8.2 ± 1.0	53.7

Seasonal population dynamics of whiteflies and aphids

Table 2 illustrates the seasonal population dynamics of whiteflies and aphids on tomato grown under *Grevillea robusta* alley cropping and sole tomato cropping systems at different crop growth stages.

The results of the study revealed that at the early vegetative state (30 DAT), populations of both whiteflies and aphids were relatively low in both cropping systems. However, even at this early stage, pest abundance was noticeably lower in the alley cropping system, with whiteflies and aphids reduced by more than half compared to sole cropping. This suggests that the presence of *Grevillea robusta* may have limited early pest colonization through habitat diversification and microclimatic modification.

During the flowering stage (60 DAT), a sharp increase in pest populations was observed in both systems, indicating favorable conditions for pest multiplication as plant biomass and nutritional quality increased. Despite this general increase, whitefly and aphid populations under alley cropping remained substantially lower than in sole tomato cropping, demonstrating the continued suppressive effect of the agroforestry system.

On the other hand, pest populations reached their peak during the fruiting stage (90 DAT). Whitefly abundance was highest at this stage, particularly in the sole cropping system, where populations were more than double those recorded in alley cropping. Aphids showed a similar trend, confirming that the fruiting stage is a critical period for sap-sucking pest pressure in tomato. The lower pest densities under alley cropping during this peak period highlight the effectiveness of *Grevillea robusta*–based systems in reducing pest build-up during economically sensitive stages of crop production.

However, at the late season stage (120 DAT), populations of both pests declined in both cropping systems. This decline may be associated with plant senescence, reduced nutritional quality of host tissues, and increased natural enemy activity. Nevertheless, pest abundance remained consistently lower in the alley cropping system, indicating sustained pest regulation throughout the cropping cycle.

Despite this, the results demonstrate that whitefly and aphid populations follow a clear seasonal pattern, with low abundance during early growth, peak infestation during flowering and fruiting stages, and decline toward crop maturity. Across all crop stages, *Grevillea robusta* alley cropping significantly suppressed pest populations compared to sole tomato cropping, emphasizing its role in enhancing ecological pest regulation and reducing pest pressure throughout the season.

Table 2. Seasonal population dynamics of whiteflies and aphids (mean no./plant)

Crop stage/Days	Whiteflies (Alley)	Whiteflies (Sole)	Aphids (Alley)	Aphids (Sole)
Early vegetative (30)	4.2	9.6	3.1	7.8
Flowering (60)	9.4	21.7	7.3	16.9
Fruiting (90)	12.3	28.4	9.6	22.1
Late season (120)	6.8	14.5	5.2	11.6

Taxonomic composition, species richness, and abundance of natural enemies

Table 3 presents the taxonomic composition, species richness, and abundance of key natural enemy groups associated with tomato grown under *Grevillea robusta* alley cropping and sole tomato cropping systems. The results clearly indicate that alley cropping supported a more diverse and abundant community of natural enemies compared to the sole cropping system.

The results of the study displayed that across all natural enemy groups, species richness was consistently higher under alley cropping. Lady beetles (Coleoptera: Coccinellidae) exhibited a species richness of four species in alley cropping compared to only two species in sole cropping. Similarly, lacewings (Neuroptera: Chrysopidae) showed three species in alley cropping but only one species in sole cropping. This enhanced diversity suggests that the structurally complex habitat created by *Grevillea robusta* provides favorable conditions such as shelter, alternative prey, and microhabitats for natural enemies.

Whereas highlighted spiders (Order Araneae; Family Araneidae) were the most diverse and abundant predator group in both systems, with six species and the highest abundance (22.8 ± 2.9 individuals per 10 plants) recorded under alley cropping. In contrast, sole tomato cropping supported only three spider species with significantly lower abundance (9.8 ± 1.4 individuals per 10 plants). The higher spider diversity and abundance under alley cropping reflect the importance of vertical and horizontal habitat complexity in supporting generalist predators.

While revealed Parasitoid wasps (Hymenoptera: Braconidae) also showed markedly higher species richness and abundance in the alley cropping system, with five species and an abundance of 15.7 ± 1.8 individuals per 10 plants, compared to only two species and 5.6 ± 0.9 individuals per 10 plants in sole cropping. This suggests that alley cropping enhances parasitoid survival and effectiveness, likely by providing nectar resources, refugia, and more stable host populations.

However, the results demonstrate that *Grevillea robusta*–based alley cropping significantly enhances both the diversity and abundance of key natural enemies of sap-sucking pests in tomato. The increased presence of predators and parasitoids under alley cropping indicates a stronger potential for biological pest control, contributing to the reduced pest populations observed in this system. These findings highlight the ecological benefits of agroforestry systems and their role in promoting sustainable pest management through conservation of natural enemies.

Table 3. Taxonomic composition, species richness, and abundance of natural enemies under different tomato cropping systems

Natural enemy	Order	Family	Alley cropping		Sole cropping	
			Species richness	Abundance (no./10 plants)	Species richness	Abundance (no./10 plants)
Lady beetles	Coleoptera	Coccinellidae	4	18.6 ± 2.1	2	7.9 ± 1.0
Lacewings	Neuroptera	Chrysopidae	3	12.4 ± 1.6	1	4.2 ± 0.6
Spiders	Araneae	Araneidae	6	22.8 ± 2.9	3	9.8 ± 1.4
Parasitoid wasps	Hymenoptera	Braconidae	5	15.7 ± 1.8	2	5.6 ± 0.9

Parasitism and predation rates of sap-sucking pests in the study area

Figure 2 compares parasitism and predation rates of major sap-sucking pests in *Grevillea robusta*–tomato alley cropping and sole tomato cropping systems. The results indicate that biological control processes were markedly stronger in the alley cropping system across all measured parameters.

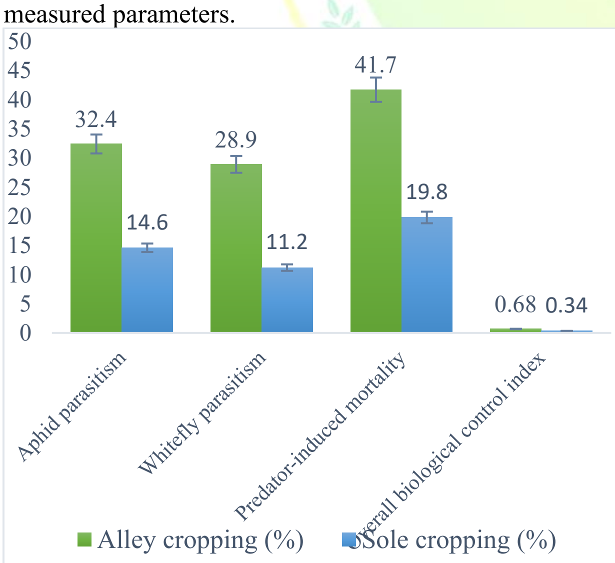

Figure 2. Parasitism and predation rates of sap-sucking pests in the study area

The results of the study illustrated that aphid parasitism was more than twice as high under alley cropping (32.4%) compared to sole cropping (14.6%). This substantial increase suggests that the diversified habitat provided by *Grevillea robusta* favors parasitoid survival and efficiency, resulting in enhanced regulation of aphid populations.

Similarly, whitefly parasitism was considerably higher in the alley cropping system (28.9%) than in sole tomato cropping (11.2%). Whiteflies are key pests in tomato production, and the elevated parasitism rates observed under alley cropping indicate improved activity of parasitoids such as Encarsia spp., likely supported by improved microclimatic conditions and alternative resources provided by the tree component.

The results of the study also indicated that predator-induced mortality was significantly higher in the alley cropping system, reaching 41.7%, compared with 19.8% in sole cropping. This difference reflects the greater abundance and diversity of generalist predators, including lady beetles, lacewings, and spiders, observed under alley cropping. The increased predator pressure contributes substantially to the suppression of sap-sucking pest populations.

The findings of the study revealed that the overall biological control index, which integrates parasitism and predation effects, was nearly double in alley cropping (0.68) compared to sole cropping (0.34). This indicates a stronger and more stable biological control function in the agroforestry system.

Overall, these results demonstrate that *Grevillea robusta*–tomato alley cropping significantly enhances both parasitoid- and predator-mediated pest suppression. The increased biological control efficiency under alley cropping explains the reduced pest densities observed in this system and underscores the role of agroforestry practices in promoting sustainable, ecologically based pest management strategies.

Tomato growth and yield parameters under different pest pressure regimes

Table 4 shows the effects of *Grevillea robusta*–tomato alley cropping and sole tomato cropping on plant growth, yield components, and pest damage. Overall, tomato plants grown under alley cropping exhibited improved growth, higher yield, and lower pest damage compared to sole cropping, suggesting a beneficial influence of the agroforestry system.

Table 4. Tomato growth and yield parameters under different pest pressure regimes

Parameter	Alley cropping	Sole cropping
Plant height (cm)	92.6 ± 4.3	85.1 ± 3.9
Leaf area index	3.4 ± 0.2	2.9 ± 0.2
Fruit number/plant	28.7 ± 2.1	21.4 ± 1.8
Average fruit weight (g)	82.5 ± 3.6	75.2 ± 3.1
Marketable yield (t ha⁻¹)	32.8 ± 1.9	25.4 ± 1.6
Pest damage index (%)	18.6	37.9

The findings of this study demonstrated that plant height was greater in alley cropping (92.6 ± 4.3 cm) than in sole cropping (85.1 ± 3.9 cm), indicating that moderate shading and improved microclimate under *Grevillea robusta* did not suppress vegetative growth. Similarly, the leaf area index (LAI) was higher in alley cropping (3.4 ± 0.2) than in sole cropping (2.9 ± 0.2), reflecting enhanced leaf development and canopy expansion, which can improve photosynthetic capacity and crop productivity.

In terms of reproductive parameters, tomato plants in alley cropping produced more fruits per plant (28.7 ± 2.1) than those in sole cropping (21.4 ± 1.8). The average fruit weight was also higher in alley cropping (82.5 ± 3.6 g vs. 75.2 ± 3.1 g), contributing to increased overall yield. Consequently, marketable yield was substantially higher under alley cropping (32.8 ± 1.9 t ha^{-1}) compared to sole cropping (25.4 ± 1.6 t ha^{-1}), representing an approximate 29% yield increase.

The results of the study revealed that the pest damage index was significantly lower in alley cropping (18.6%) than in sole cropping (37.9%), consistent with the enhanced abundance and diversity of natural enemies observed in the alley cropping system. Reduced pest damage likely contributed to the higher fruit number, weight, and overall yield in alley cropping, highlighting the role of biological pest regulation in maintaining crop productivity.

At the same time, these results indicate that *Grevillea robusta*–tomato alley cropping improves both growth and yield performance of tomato, even under varying pest pressure. The combination of enhanced natural pest control, moderated microclimate, and improved plant growth conditions makes alley cropping a promising agroecological strategy for sustainable tomato production.

The consistently lower abundance of all major sap-sucking pests under *Grevillea robusta*–tomato alley cropping demonstrates the strong regulatory effect of agroforestry systems on pest populations. Reductions ranging from 53.7% to 57.8% (Table 1) suggest that increased plant diversity and structural complexity disrupted pest colonization and population growth. Similar findings have been reported in diversified cropping systems, where agroforestry reduced herbivore pressure by altering pest movement and resource availability (Bianchi et al., 2019; Letourneau et al., 2020).

The significant reduction of Bemisia tabaci under alley cropping supports previous studies showing that whiteflies are highly sensitive to habitat heterogeneity. Tree presence can interfere with host plant detection through visual and olfactory disruption while enhancing natural enemy activity (Reddy et al., 2021). Reduced whitefly populations in agroforestry systems have also been linked to improved microclimatic conditions and increased parasitoid effectiveness (Dáder et al., 2022).

Aphids showed the highest reduction (57.8%) under alley cropping, indicating strong biological regulation. Aphids are known to respond rapidly to predator and parasitoid pressure, particularly in systems with high plant diversity (Snyder, 2019). Increased parasitism rates observed in alley cropping (Figure 1) likely contributed to aphid suppression, consistent with studies demonstrating enhanced aphid control in tree-based intercropping systems (Karp et al., 2018).

Thrips populations were significantly lower under alley cropping, reflecting their preference for hot, dry, and simplified environments. Agroforestry systems moderate temperature and increase humidity, creating less favorable conditions for thrips development (Reitz et al., 2020). Additionally, predators such as lacewings and spiders, which were more abundant in alley cropping (Table 3), are effective thrips suppressors (Mouden et al., 2019). The reduced abundance of *Tetranychus urticae* under alley cropping aligns with evidence that mites thrive under high temperature and low humidity. Tree shade and increased canopy moisture likely suppressed mite reproduction while favoring predatory mites and generalist predators (Zhang et al., 2021). Similar reductions in mite populations have been reported in shaded agroforestry systems compared to open monocultures (Pumariño et al., 2015).

Although leafhoppers are highly mobile, their populations were still reduced by 53.7% under alley cropping. This suggests that habitat complexity can affect even mobile pests by disrupting host plant continuity and increasing exposure to predators (Tscharntke et al., 2021). The presence of trees may also alter wind patterns and visual cues used by leafhoppers for host location.

Whitefly and aphid populations increased from vegetative to fruiting stages in both systems (Table 2), reflecting improved host suitability as plants matured. However, pest populations remained consistently lower under alley cropping across all growth stages. This indicates that agroforestry provides continuous pest regulation rather than stage-specific suppression, consistent with findings by Poveda et al. (2025) on perennial-based cropping systems.

Peak pest densities during flowering and fruiting stages highlight these phases as critical intervention points. The lower pest abundance under alley cropping during these economically sensitive stages suggests that agroforestry can protect yield more effectively than sole cropping (Isbell et al., 2017). This is particularly important for sap-sucking pests that directly affect fruit set and quality.

The higher species richness of natural enemies under alley cropping (Table 3) confirms that *Grevillea robusta* increased habitat suitability for beneficial arthropods. Structural diversity, refuge availability, and alternative prey are key drivers of natural enemy diversity in agroforestry systems (Schipanski et al., 2019; Rosa-Schleich et al., 2023).

Spiders were the most abundant and diverse predator group under alley cropping, highlighting their importance in pest suppression. As generalist predators, spiders respond positively to habitat complexity and play a crucial role in regulating multiple pest species simultaneously (Nyffeler & Sunderland, 2020). Their higher abundance explains the increased predator-induced mortality observed in alley cropping.

Higher parasitoid richness and abundance under alley cropping, along with increased parasitism rates (Figure 1), indicate improved biological control services. Trees may provide nectar, shelter, and stable microclimates that enhance parasitoid longevity and host-searching efficiency (Gurr et al., 2017; Tschumi et al., 2021).

The nearly doubled biological control index under alley cropping reflects a more stable and resilient pest regulation system. The combined effects of predators and parasitoids reduced pest resurgence, supporting the theory that diverse enemy assemblages provide more effective control than single natural enemy groups (Crowder & Jabbour, 2019).

Improved plant height, leaf area index, fruit number, and yield under alley cropping (Table 4) demonstrate that pest suppression translated into tangible agronomic benefits. Reduced pest damage allowed plants to allocate more resources to growth and reproduction, consistent with findings from agroecological intensification studies (Tamburini et al., 2020).

Overall, the findings demonstrate that *Grevillea robusta*–tomato alley cropping enhances ecological pest regulation while improving yield and reducing pesticide reliance. This supports agroforestry as a viable component of integrated pest management (IPM) and climate-resilient agriculture in smallholder systems (FAO, 2022; Perfecto et al., 2019). Adoption of such systems in Nyagatare District could contribute to sustainable intensification and environmental conservation.

CONCLUSION

This study evaluated the role of *Grevillea robusta*–tomato alley cropping in regulating populations of sap-sucking pests, enhancing natural enemy diversity and abundance, and improving tomato growth, yield, and crop health in Nyagatare District, Rwanda. The results clearly demonstrated that alley cropping significantly reduced the abundance of major sap-sucking pests, including whiteflies, aphids, thrips, spider mites, and leafhoppers, compared with sole tomato cropping. Pest reductions of over 50% across all species indicate that the agroforestry system provided effective and consistent pest suppression throughout the cropping season.

The study further showed that *Grevillea robusta* alley cropping supported a more diverse and abundant community of natural enemies, including predators and parasitoids, which played a key role in pest regulation. Higher species richness, increased predator and parasitoid abundance, and elevated parasitism and predation rates under alley cropping contributed to a stronger and more stable biological control function. These ecological interactions explain the reduced pest densities observed in the agroforestry system and highlight the importance of habitat complexity in enhancing ecosystem services for pest management.

In addition to improved pest regulation, tomato plants grown under alley cropping exhibited superior growth performance, higher marketable yield, and lower pest damage compared to sole cropping. The moderated microclimate, reduced pest pressure, and enhanced biological control under *Grevillea robusta*–based systems collectively contributed to improved crop productivity. Overall, the findings provide strong experimental evidence that *Grevillea robusta*–tomato alley cropping is an effective, environmentally sustainable strategy for integrated pest management and productivity enhancement in smallholder tomato production systems in Nyagatare District.

Recommendations

Encourage farmers in Nyagatare and similar zones to adopt *Grevillea robusta*–tomato alley cropping as part of IPM to reduce pesticide use, cut costs, and improve environmental and human health. Combine alley cropping with pest-resistant varieties, conservation of beneficial insects, and proper fertilizer and water management to boost pest control, resilience, and tomato yields. Conduct long-term, multi-season studies to assess pest control stability, economic benefits, farmer adoption, and impacts on soil fertility and carbon sequestration.

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CONFLICT OF INTEREST

The author declares that there is no conflict of interest regarding the publication of this manuscript.

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