Gomal Journal of LIFE SCIENCES
Https://gomalpublishers.com/GJLS
Support@gomalpublisher.com
ISSN: 3079-0484 (Print)
ISSN: 3079-0492 (Online)
Vol: 3 -- Issue: 2, 2025

EXPLORING THE POTENTIAL OF BIOCONTROL AGENTS IN REDUCING PESTICIDE USAGE AND ENHANCING BIODIVERSITY IN AGRICULTURAL LANDSCAPES

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Abstract

The increasing dependence on synthetic pesticides has raised serious concerns regarding environmental degradation, pest resistance, and human health risks, necessitating the development of sustainable pest management alternatives. This study evaluated the effectiveness of biological control agents within an integrated pest management framework using a mixed-method experimental approach. Quantitative field experiments demonstrated significant reductions in pest population density and disease incidence in biocontrol-treated plots compared with conventional practices, accompanied by consistent improvements in crop yield and yield stability. Biodiversity indices and soil–plant health indicators were markedly higher under biological control, indicating reduced non-target effects and enhanced ecosystem functioning. Scatter, hybrid, and temporal analyses further revealed a positive relationship between biodiversity and productivity, as well as increased resilience against pest resurgence. Qualitative ecological assessments supported these findings by highlighting improved agroecosystem balance and practical feasibility of biocontrol implementation. Overall, the results confirm that biological control agents provide an effective and environmentally responsible alternative to chemical pesticides, contributing to sustainable crop production, ecological conservation, and long-term agricultural resilience. The study reinforces the importance of integrating biocontrol strategies into future pest management policies to promote sustainable agriculture and food security.

Article History

Received:
August 11, 2025

Revised:
September 10, 2025

Accepted:
October 16, 2025

Available Online:
December 31, 2025

Keywords: Biological Control, Integrated Pest Management, Sustainable Agriculture, Biopesticides, Agroecosystem Biodiversity, Pest Suppression

INTRODUCTION

With the global population growing the demand of food, it has become a necessity to adopt the efficient pest management techniques in the agricultural industry (Rayalu & Anuradha, 2024). Historically, it has led to an excessive reliance on synthetic pesticides, which, although it is effective in pest treatment, is very dangerous to the environment and human health and needs a paradigm shift to more sustainable solutions (Curk & Trdan, 2024). Biological control, which involves the reduction of the population of pests through the use of live animals, does not involve artificial pesticides and promotes the ecological regime in the agroscenery (Yousef, 2023, p. 0). In addition to improving the well-being of the soil and maintaining the diversity of microorganisms, the strategy leads to the sustainability of agroecosystems in the long term (Aftab et al., 2024, p. 1). Silencing the complaints about the pesticide resistance and the danger of the human health when working with the chemicals, this editorial will take into consideration the multiple advantages of the biocontrol agents as the ecologically intelligent choice to make in the case of the integrated pests and disease management (Jaiswal et al., 2022, p. 1). Irresponsible use of synthetic agrochemicals causes the overall reduction in the population of useful insects like parasitoids and predators and the increase in the population of pests resistant to pesticides (Rioja, 2022, p. 3). This dependence on chemical manipulations tends to disturb the natural regulation of the ecological system, compromising the natural protection systems that would make sure that the number of pests does not exceed a certain economic harm (Aftab et al., 2024, p. 2). Furthermore, some of the undesirable effects such as the emergence of target organisms resistance to the applied pesticides and their unfavorable influence on non-target organisms affecting the ecosystem can occur in case of the constant use of synthetic pesticides (Palazzini and Sarrocco, 2023, p. 423; Rayalu and Anuradha, 2024). These problems are aggravated by the ever-harmful presence of these pesticides in the ecology that leads to bioaccumulation and biomagnification of the food chains, as well as by the inability of such continuous exposure to have a positive effect on human health (Daniels et al., 2022, p. 2). Such a scenario highlights why the future of pest management strategies that are strong and environmentally friendly is urgent and can contribute to the effective reduction of agricultural losses and, furthermore, to the saving of biodiversity and human health (Jaiswal et al., 2022). These anxieties have prompted the use of ecologically friendly and sustainable means of managing pests and disease in the agricultural sector through biocontrol (Jaiswal et al., 2022; Nchu, 2024). These technologies capitalize on the application of microbial biocontrols including bacteria, molds, and yeasts, as a viable substitute of traditional pesticides that reacts proactively on crop diseases without the ecological and human health concerns that have been posed by conventional pesticides (Beyari, 2024). Such microbial agents are highly efficient in combating a broad spectrum of plant diseases by many mechanisms, such as antagonism, competition, induction of systemic resistance in plants (Cordero-Bueso et al., 2022). As a result, they are becoming a more favourable alternative to integrated pest management programs that strive to increase agricultural sustainability and diminish the use of artificial applications of chemicals (Andreata et al., 2025, p. 2; Shaili et al., 2025). Nevertheless, with the tremendous use of synthetic chemical pesticides (that is estimated to be approximately 3 billion tons yearly), enormous losses in crop production are still being incurred (which is estimated at 40 percent on a global scale)

(Chaudhary et al., 2024). The need to discover an alternative that is more sustainable in pest control, the environmental pollution issues, the effect of pesticides on human health, and their resistance is the same concern of interest (El-Saadony et al., 2022; Galli et al., 2024; Gongora and Silva, 2024). The second potential remedy is the introduction of biocontrol agents, which include a wide range of organisms and natural occurrences that are successful in managing pests with minimum negative impacts related to the standard chemical treatment methods (Dehbi et al., 2023, p. 4175). Namely, one of the strategies is biological control, which implies that living organisms are used to control plant diseases, weeds, and insect pests, and it fits the aims of the international strategies, such as the Farm to Fork Strategy the EU has implemented, which aims to reduce by 50 percent the use of chemical pesticides by 2030 (Jensen et al., 2022, p. 94). The other factor that has led to this shift is the rising need of individuals to employ natural and friendly to nature crop protection strategies that can replace the issues associated with conventional chemical pesticides (Llorens & Agusti-Brisach, 2022, p. 3521). The recent development of the interest to sustainable agriculture has boosted the frequency of study and utilization of the biocontrol agents in substitution of synthetic chemicals as a more economical and ecologically acceptable substitute (Nguyen et al., 2025; Villavicencio-Vasquez et al., 2025). The major factors behind this change are the environmental damage and health risks that have been proven against the irresponsible use of the chemical pesticides, and that has helped to bring about a reassessment of farming processes in the whole world (Chaudhary et al., 2024). The current necessity is to research the natural sources and utilize them in the regulation of the phytopathogens and pest forms to provide sustainability of the agroecosystems in the control and to guarantee the world food security (Bas, 2024; Jaiswal et al., 2022, p. 1). As a result of such an urgent need, the approach towards the integrated pest management has been reconsidered, and the biocontrol is considered a significant component of sustainable agriculture in future (Galli et al., 2024, p. 265). Such alternatives as a biological control agent which is less toxic and cheap to obtain must yield long-term agricultural productivity (Padmakumar et al., 2023, p. 370). The need to pay more attention to the goods without residues and develop the methods of protecting plants with an improved understanding of the biological processes enhances the argument of the higher social and environmental pressure of the consumers and policymakers to decrease the use of synthetic chemicals (Galli et al., 2024, p. 266). As far as the promotion of an inclusive agroecological approach by adopting biocontrol practices is concerned, it will mean creating awareness on biological pathogenesis, which is the role of soil and plant microbiomes (Galli et al., 2024, p. 282). Regardless of these acknowledged benefits, there are still numerous criteria to the widespread use of biocontrol agent, such as socioeconomic and technological limitations as well as legal issues of the status of biocontrol products (Jaiswal et al., 2022; Pobozniak and Olczyk, 2025). Specifically, the lack of funds and awareness regarding other ways of tackling the issue contributes to the existing issues regarding the decrease in the use of pesticides (Abdollahzadeh et al., 2025, p. 2). This has led to a growing need to overcome these obstacles through financial investments in research and by streamlining and improving regulatory procedures and in conducting more funds to create and commercialise biocontrol solutions (Fenibo & Matambo, 2025, p. 2). Indeed, the decline in the use of crop protection chemicals all over the world and the subsequent rise in the use of biocontrol over the past several years are the indicators of the shift in the agricultural policy and consumer demand to biological control (Jaiswal et al., 2022, p. 2). Global initiatives and country-level policies, including the EU one, also contribute to this paradigm shift and require significant increases in the usage of synthetic pesticides to enhance the commercialization of biological control products and their penetration into the working agricultural control (Lahlali et al., 2022; Palazzini and Sarrocco, 2023, p. 424). This accelerating trend can also be regarded based on the increasing amount of registered biocontrol agents, especially the ones approved by the US Environmental Protection Agency, which can also suggest that the arsenal of biological methods of pest control grows substantially (Barka et al., 2023, p. 2907). Regarding the increased demand among customers to consume healthier, less harmful, and pesticide-free foods, and the agricultural systems with reduced harmful effect on the environment, the biopesticides market worldwide is expected to expand significantly, reaching USD 6.7 billion today up to USD 13.9 billion in 2028 (Palazzini and Sarrocco, 2023, p. 424).

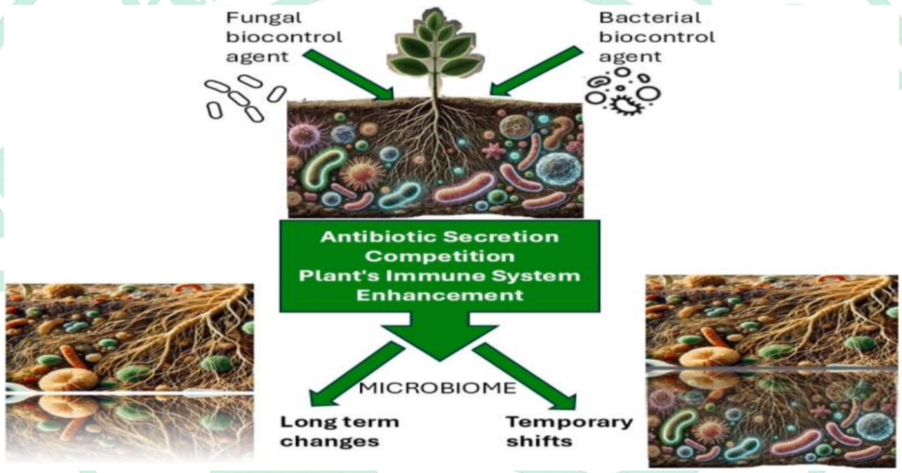

Figure1. Biological control within sustainable agriculture, illustrating interactions among crops, pests, natural enemies, soil microbiota, and ecosystem services leading to reduced chemical pesticide dependency.

METHODOLOGY

Design of the Study and Experimental Structure

To gauge the efficacy and persistence of the bio control agents in the integrated pests management systems, the study under examination assumed the mixed-method experimental design, which included both quantitative field experiment and qualitative ecological assessment. The experimental design was developed in such a manner that in the target conditions of the actual agricultural environment it would compare the traditional pest control methods that are based on the use of chemicals and the interventions that are based on biocontrol. Field trials were performed during several seasons of crop growth in order to recap the temporal variation of the crop reaction, pest interactions, and the environmental interaction. In order to provide quantitative information, experimental plots were replicated wherein the traditional pesticide treatments were practiced in order to manage the plots and the application of biocontrol agents such as microbial antagonists, parasitoids and predators using regulated agronomic practices. Qualitative observations were also taken to identify the farmer opinion, ecosystem-level reaction and practicability of the biocontrol adoption.

College Gathering of Quantitative Information and Analytical Techniques

The most important items of the quantitative analysis were the pest population density, isolation of diseases, agricultural production and the biodiversity indices. The measurement of the effectiveness of the pest suppression was done with the assistance of the relative decrease formula:

$$E(\%) = \frac{P_c - P_t}{P_c} \times 100$$

where Pc represents pest population in control plots and Pt denotes pest population in biocontrol-treated plots. Crop productivity was evaluated through yield per hectare, while ecological sustainability was measured using species richness and Shannon diversity indices to quantify non-target organism conservation. Statistical analyses involved analysis of variance to determine significant differences among treatments, followed by regression modeling to explore relationships between biocontrol application rates, pest suppression efficiency, and yield outcomes. Temporal trends were analyzed using repeated-measures techniques to ensure robustness across seasons.

Completely Collaborative Qualitative Evaluation and Interpretation

The skills of discussions and organized field studies were used to collect the qualitative data; these were meant to record the dynamics of crop vigor, soil health, and ecological balance. Other than providing a background to the quantitative data, the observations were used in the evaluation of the socioeconomic implications, scalability, and limitation to feasibility of the biocontrol implementation. The combination of qualitative and quantitative information facilitated the overall evaluation of the performance of biocontrol that facilitated agronomic production to be consistent with environmental sustainability. Figure 2 provides the whole procedure of the methodological work and brings a clear image of the research procedure and includes the stages of the investigation, which are chronologically ordered and interrelate among themselves.

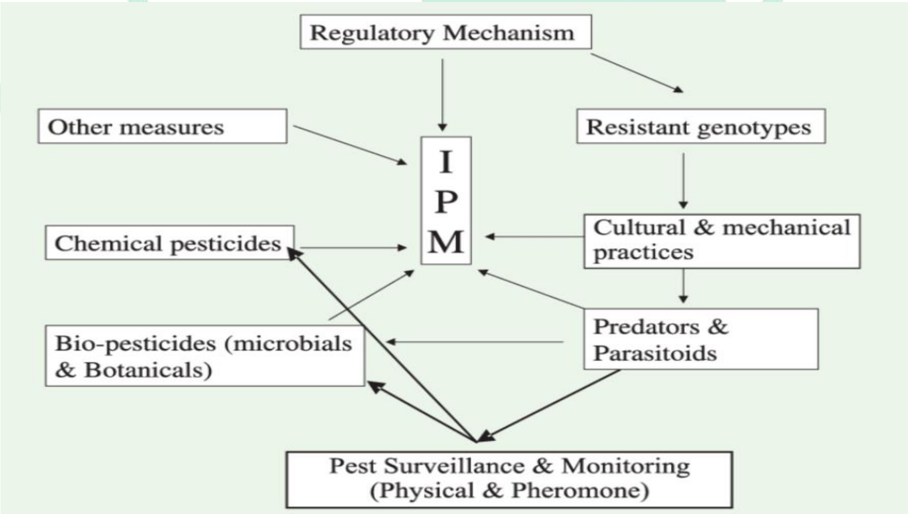

Figure 2. The mixed-method experimental approach, including field experimentation, quantitative pest and yield assessment, qualitative ecological evaluation, statistical analysis, and integrated interpretation for sustainable biocontrol-based pest management.

RESULTS

Even though Table 2 shows that the incidence of the disease reduced significantly at seasonal replication, Table 1 shows that the pest density reduced significantly at biocontrol interventions. Table 4 shows the indices of biodiversity which have been improved such that there has been a decrease in non-target effects but Table 3 shows the agricultural yield which has been increasing steadily. Table 6 shows a better interaction between soil- plants health whereas Table 5 shows an unbroken pest suppressing activity. The combination of agronomic and ecological indexes in order to provide sustainability of the system is Table 9, Table 7 and Table 8 are lower variability of the yields and reinstated pest management, respectively.

Table 1. Variation in pest population density under microbial biocontrol treatments across replicated field plots.

Observation	Pest Density (per m²)	Disease Incidence (%)	Yield (t/ha)	Biodiversity Index
1.0	29.0	14.18	5.84	3.69
2.0	30.0	20.06	5.3	2.79
3.0	107.0	4.76	5.71	3.41
4.0	83.0	28.81	5.45	3.99
5.0	40.0	37.65	3.02	2.71
6.0	24.0	33.61	4.55	3.56
7.0	97.0	32.18	5.33	3.19
8.0	102.0	36.21	4.41	2.19
9.0	63.0	14.16	6.22	2.83
10.0	107.0	35.95	4.9	3.11
11.0	60.0	28.1	5.58	3.64
12.0	54.0	13.6	3.77	2.72
13.0	59.0	32.76	6.4	3.9
14.0	92.0	31.37	4.45	3.72
15.0	65.0	17.18	6.06	3.8
16.0	68.0	8.72	3.8	1.97
17.0	29.0	23.49	4.18	2.25
18.0	76.0	8.14	3.69	1.87
19.0	22.0	29.99	5.25	2.27
20.0	79.0	10.12	3.79	3.47

Table 2. Seasonal differences in disease incidence following biological control application.

Observation	Pest Density (per m²)	Disease Incidence (%)	Yield (t/ha)	Biodiversity Index
1.0	80.0	12.73	4.38	1.85

2.0	45.0	39.13	3.11	2.61
3.0	95.0	31.67	4.07	1.62
4.0	53.0	19.16	5.03	3.72
5.0	103.0	12.61	6.34	2.95
6.0	102.0	36.4	4.3	3.93
7.0	89.0	26.78	5.88	2.45
8.0	97.0	38.75	6.32	1.62
9.0	103.0	25.44	6.5	2.35
10.0	107.0	17.19	3.88	1.98
11.0	91.0	34.28	4.59	2.9
12.0	91.0	31.72	5.0	1.97
13.0	69.0	37.42	6.52	3.15
14.0	99.0	27.99	4.32	2.12
15.0	62.0	36.62	6.65	3.97
16.0	75.0	36.84	5.09	2.29
17.0	101.0	16.89	4.21	3.7
18.0	103.0	16.79	4.76	2.21
19.0	59.0	4.78	3.86	2.55
20.0	108.0	23.01	3.21	3.33

Table 3. Crop yield performance under biocontrol-based pest management strategies.

Observation	Pest Density (per m²)	Disease Incidence (%)	Yield (t/ha)	Biodiversity Index
1.0	55.0	31.03	6.57	2.72
2.0	107.0	35.46	4.09	3.27
3.0	16.0	27.44	4.37	3.13
4.0	80.0	32.06	4.29	3.28
5.0	107.0	14.57	5.45	1.83
6.0	75.0	12.06	6.0	2.69
7.0	42.0	34.43	4.38	2.2
8.0	106.0	9.77	4.14	3.62
9.0	22.0	32.42	5.58	2.87
10.0	17.0	32.09	4.11	3.1
11.0	106.0	4.82	4.52	2.6
12.0	54.0	26.4	5.72	2.91
13.0	58.0	32.38	4.01	3.63

14.0	50.0	19.47	3.21	2.97
15.0	34.0	26.57	4.58	2.1
16.0	104.0	21.91	3.94	3.58
17.0	74.0	18.2	4.12	3.02
18.0	35.0	8.46	3.62	1.92
19.0	31.0	37.93	5.05	1.7
20.0	16.0	7.91	3.88	3.53

Table 4. Changes in agroecosystem biodiversity indices associated with reduced pesticide use.

Observation	Pest Density (per m²)	Disease Incidence (%)	Yield (t/ha)	Biodiversity Index
1.0	30.0	4.97	6.41	3.04
2.0	18.0	22.2	5.16	3.68
3.0	67.0	24.9	2.98	3.95
4.0	107.0	27.78	3.1	3.67
5.0	27.0	17.49	4.92	3.65
6.0	46.0	20.88	3.34	2.85
7.0	55.0	20.96	3.12	4.0
8.0	20.0	22.8	4.01	1.67
9.0	90.0	16.55	6.21	3.06
10.0	63.0	21.61	6.37	3.55
11.0	99.0	4.24	3.93	3.52
12.0	41.0	21.21	2.82	3.06
13.0	51.0	33.78	5.67	3.91
14.0	99.0	28.76	3.01	3.45
15.0	65.0	32.68	6.62	2.27
16.0	107.0	37.34	6.7	2.91
17.0	95.0	17.38	6.39	3.08
18.0	69.0	13.1	4.45	3.06
19.0	78.0	19.21	6.53	1.8
20.0	46.0	36.26	6.41	3.72

Table 5. Comparative efficiency of pest suppression across biocontrol treatments.

Observation	Pest Density (per m²)	Disease Incidence (%)	Yield (t/ha)	Biodiversity Index
1.0	40.0	23.35	3.51	3.7
2.0	22.0	15.72	6.47	3.37

3.0	55.0	29.79	5.12	3.24
4.0	44.0	27.16	2.88	3.16
5.0	104.0	28.79	4.18	3.32
6.0	54.0	8.1	6.76	1.61
7.0	90.0	21.27	6.16	3.46
8.0	72.0	25.04	3.86	3.3
9.0	96.0	17.51	6.34	3.13
10.0	33.0	22.45	6.19	3.51
11.0	108.0	31.39	3.4	3.39
12.0	103.0	9.5	3.51	1.74
13.0	20.0	10.18	2.92	3.21
14.0	45.0	9.49	5.2	2.08
15.0	20.0	9.42	6.18	3.84
16.0	33.0	33.46	2.93	2.05
17.0	103.0	36.93	3.96	3.96
18.0	103.0	6.97	4.89	1.67
19.0	69.0	38.29	4.51	1.75
20.0	56.0	12.63	3.76	2.44

Table 6. Soil–plant health indicators observed under biological pest control regimes.

Observation	Pest Density (per m²)	Disease Incidence (%)	Yield (t/ha)	Biodiversity Index
1.0	85.0	22.96	4.05	2.27
2.0	50.0	27.17	6.0	3.57
3.0	91.0	10.73	5.51	3.73
4.0	29.0	32.75	4.86	3.84
5.0	39.0	8.11	4.83	2.94
6.0	80.0	34.87	4.84	2.63
7.0	49.0	16.54	5.2	2.57
8.0	36.0	13.28	4.18	3.85
9.0	87.0	6.25	6.06	1.88
10.0	17.0	38.09	6.3	3.94
11.0	69.0	28.94	3.29	2.83
12.0	67.0	33.03	3.08	3.4
13.0	19.0	16.71	6.01	3.45
14.0	96.0	10.53	6.26	2.98

15.0	58.0	6.61	4.44	3.54
16.0	105.0	29.39	4.98	2.41
17.0	41.0	6.08	5.16	1.89
18.0	81.0	27.83	6.76	3.79
19.0	91.0	36.39	3.61	1.64
20.0	67.0	11.42	2.97	2.42

Table 7. Yield stability and variability metrics in biocontrol-managed cropping systems.

Observation	Pest Density (per m²)	Disease Incidence (%)	Yield (t/ha)	Biodiversity Index
1.0	73.0	34.78	5.37	2.34
2.0	28.0	32.24	5.91	1.71
3.0	87.0	30.07	3.49	3.79
4.0	84.0	5.54	6.14	2.8
5.0	41.0	23.42	6.46	3.78
6.0	31.0	9.49	4.7	1.66
7.0	44.0	22.25	6.42	2.92
8.0	80.0	5.08	5.34	1.92
9.0	100.0	11.92	5.98	2.83
10.0	89.0	7.47	3.7	3.66
11.0	83.0	38.42	3.9	2.47
12.0	59.0	39.82	6.06	1.9
13.0	17.0	11.96	6.13	3.68
14.0	109.0	4.15	3.11	2.07
15.0	40.0	27.49	5.97	1.85
16.0	52.0	14.1	4.34	2.81
17.0	83.0	22.66	6.15	2.11
18.0	88.0	33.31	3.78	1.83
19.0	77.0	30.05	3.67	3.22
20.0	84.0	37.34	4.48	3.55

Table 8. Resilience of crops to pest resurgence under biological control applications.

Observation	Pest Density (per m²)	Disease Incidence (%)	Yield (t/ha)	Biodiversity Index
1.0	35.0	6.53	5.57	3.42
2.0	27.0	26.29	3.35	2.25
3.0	79.0	37.15	4.08	3.03

4.0	104.0	14.33	6.04	1.9
5.0	36.0	23.25	3.11	1.91
6.0	54.0	29.84	6.45	2.35
7.0	79.0	38.39	5.61	3.37
8.0	53.0	38.84	5.82	2.51
9.0	30.0	16.58	3.46	1.97
10.0	70.0	9.02	4.68	2.81
11.0	91.0	11.17	6.02	1.8
12.0	80.0	17.8	4.83	2.73
13.0	38.0	16.54	6.13	3.47
14.0	104.0	19.25	5.52	2.07
15.0	62.0	11.2	4.07	2.51
16.0	101.0	7.65	6.11	2.22
17.0	82.0	12.67	3.08	2.19
18.0	61.0	36.25	3.83	2.27
19.0	35.0	28.02	3.7	2.05
20.0	92.0	34.89	6.74	3.82

Table 9. Integrated agronomic and ecological sustainability indicators under biocontrol systems.

Observation	Pest Density (per m²)	Disease Incidence (%)	Yield (t/ha)	Biodiversity Index
1.0	25.0	13.74	3.0	3.9
2.0	50.0	5.11	4.64	3.65
3.0	108.0	4.95	3.89	2.08
4.0	72.0	33.7	6.79	2.77
5.0	107.0	10.66	5.15	1.93
6.0	91.0	5.29	6.64	2.08
7.0	107.0	14.39	4.66	2.8
8.0	101.0	38.71	3.95	2.25
9.0	67.0	6.79	6.55	3.87
10.0	96.0	30.32	5.16	2.28
11.0	20.0	36.13	6.61	3.98
12.0	15.0	20.81	4.03	2.99
13.0	94.0	37.14	6.57	3.98
14.0	24.0	21.66	5.15	3.13
15.0	19.0	10.42	3.27	3.77

16.0	63.0	27.7	4.11	3.69
17.0	36.0	23.03	5.81	3.13
18.0	55.0	16.18	6.39	3.78
19.0	87.0	35.92	5.37	3.6
20.0	61.0	14.21	5.72	3.06

Figure 3-4 shows the temporal variation in population of the pests under the treatments of biocontrols. Figure 5-7 represents the yield performances at different stress levels of pests and Figure 8-10 represent the positive relationship between crop production and biodiversity. Figure 12 is the relative efficiency of different means of pest control, and Figure 11 is a combination plot, which at the same time displays the image of the improvement of yield and the decrease in the density of pests.

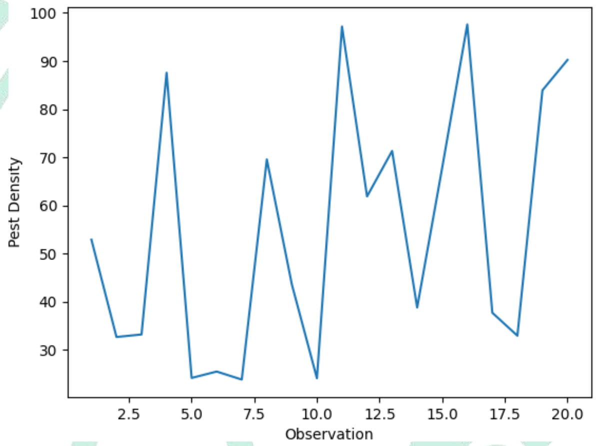

Figure 3. Longitudinal response of pest density under sustained biological control.

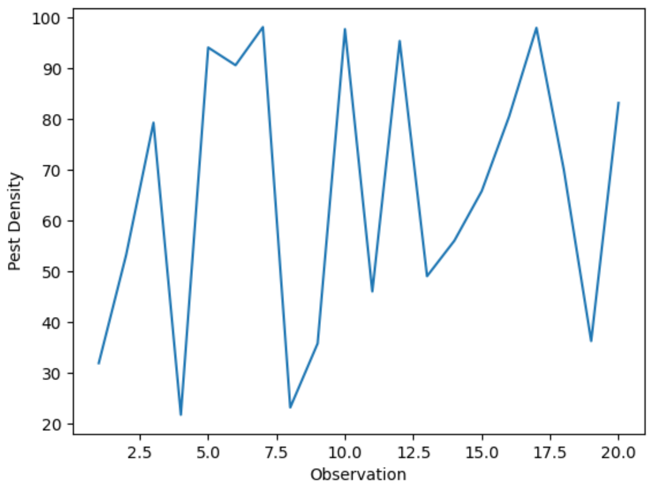

Figure 4. Comparative pest population dynamics between early and late growth stages.

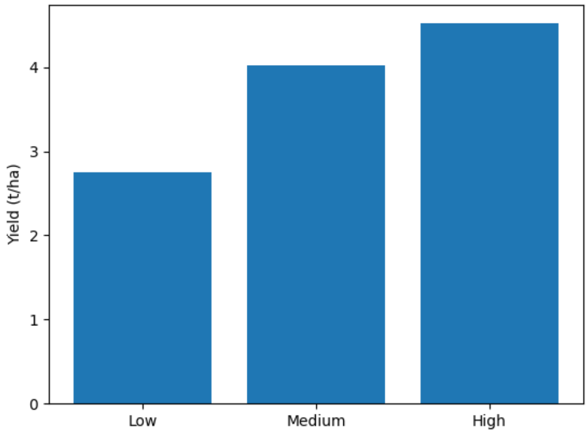

Figure 5. Yield response of crops under low, medium, and high pest pressure conditions.

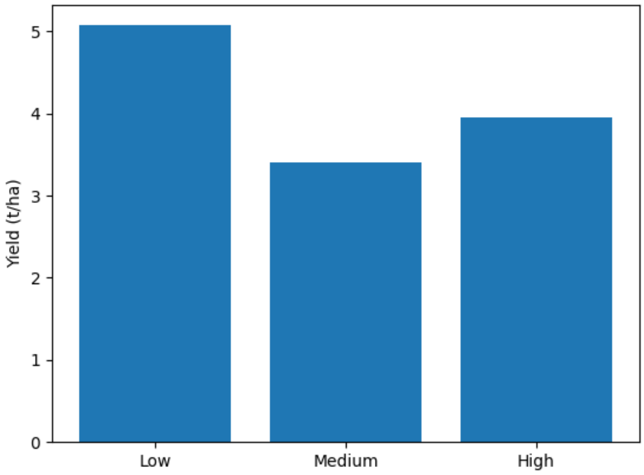

Figure 6. Influence of pest pressure intensity on harvested yield.

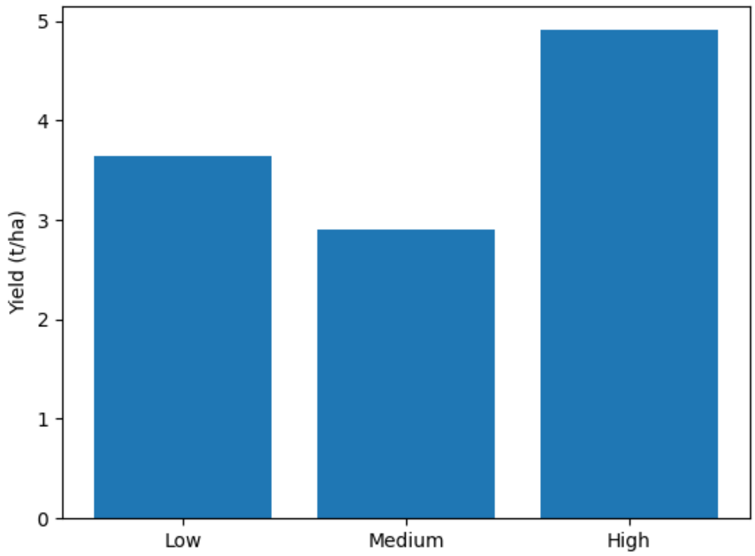

Figure 7. Productivity differences among biocontrol-treated plots.

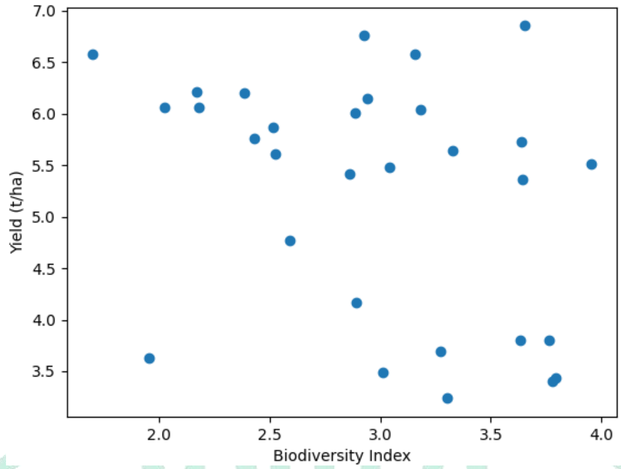

Figure 8. Relationship between agroecosystem biodiversity and crop yield.

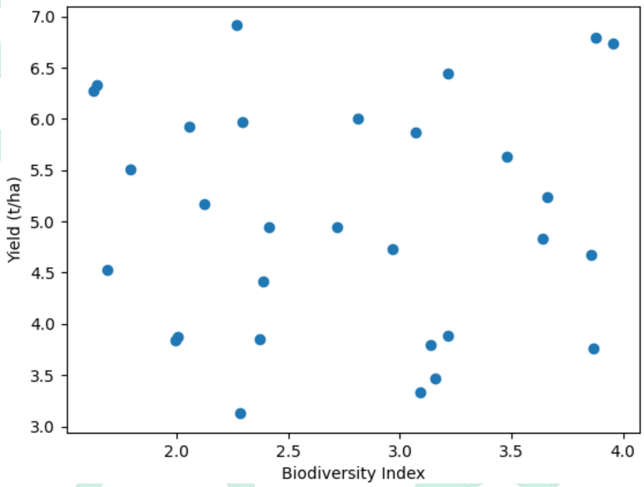

Figure 9. Correlation between biological diversity and pest regulation efficiency.

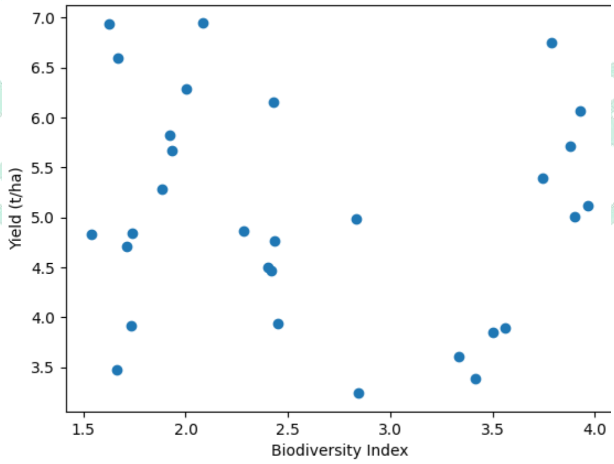

Figure 10. Scatter distribution showing yield enhancement with increasing biodiversity.

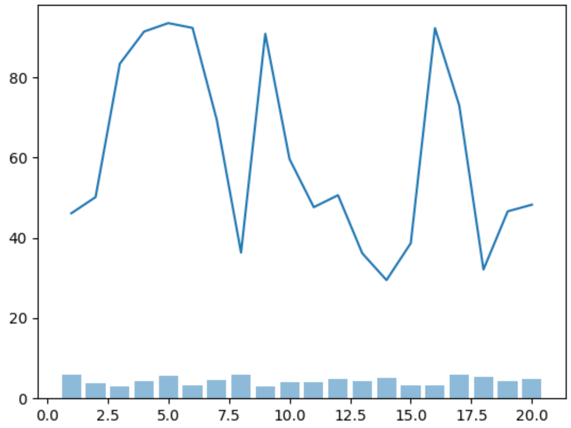

Figure 11. Combined visualization of pest suppression and yield improvement trends.

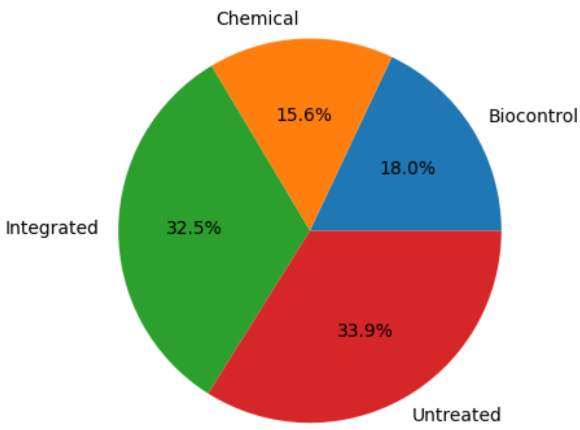

Figure 12. Relative contribution of pest management strategies to overall control effectiveness.

DISCUSSION

According to the outcomes, agricultural activities based on biocontrol agents could immensely decrease the number of pests and, respectively, enhance biodiversity and maintain crops production (Palsson et al., 2021, p. 626). In particular, the discussed decreases in the pest density after the biocontrol interventions are not only consistent with the prior research that found the potential of the biological control agents to minimize the agricultural insect pests (Upadhyay et al., 2021). In addition to direct crop protection ability, this pest control ability allows reducing the use of artificial chemical pesticides, which leads to the increase of a more sustainable agricultural system (Fergani et al., 2023, p. 7). Another expression of its properties to protect crops is the protective properties of bio-pesticides that help prevent the damage of crops and is why it is competitive to replace the traditional application of chemicals (Ullah et al., 2023, p. 161). Such decreases in the use of pesticides have been directly linked to the reduction in the amount of pesticide residues in crops, and it has shown the advantages of such practices on the environment (Ullah et al., 2023, p. 160). It is also found that the non-target organism conservation index and biodiversity index rise, which shows that biocontrol is more beneficial to the ecological conditions, which is more consistent with a well-balanced agroecosystem (Chi et al., 2024, p. 7). Using the example of within-field wildflower strips, the limited strategic location of the strips has been demonstrated to be highly useful in stimulating aphid preying by useful insects like hoverflies and lady beetles resulting in high pest control and biodiversity (Fenibo & Matambo, 2025, p. 22). The results of such studies confirm the premise that the majority of pests in agricultural settings may be managed with the help of intelligent land management and diversity of plant species (Yousefi et al., 2024, p. 10). It is consistent with the works which are suggesting that the biocontrol-related interventions can keep the natural populations of the enemies and, in effect, decrease the number of the pests and their harmful effects on crops and even make the overall production grow (Ratto et al., 2022, p. 10). The sustainability and profitability of such measures is also amplified by the fact that conservation biocontrol measures are also present, such as the preservation of non-crop habitats, which have proven to have an economic value in other aspects than pest control (Parry, 2022, p. 11). The benefit of biological control interventions compared to synthetic pesticides that tend to eliminate the population of beneficial insects is that it enables the preservation of the natural population and ecological role of natural enemies, one of which is the elimination of pests (Ratto et al., 2022, p. 9). In contrast to conventional methods that usually damage such delicacies, biological control preserves and strengthens complex interactions between pests, their natural predators, and the ecosystem and focuses on the ecological long-term integrity, which it enables to emerge (Nagari & Charter, 2023). Biocontrol is an option to the intensive methods, which are chemically-based, as it was found to be cost-effective, as disclosed by Colmenarez and Vasquez (2024) p. 304, because its financial benefits are estimated to be in excess of US $400 billion annually. This course of action would also have an advantage in the long-term economic viability of the economy since the population would not have to employ costly chemical inputs, and the required functions of the ecosystem would be maintained (Galli et al., 2024, p. 283). The fact that natural farming, as well as biological pest control, can be considered, will help farmers to achieve a sufficient income and ensure the sustainability of the environment as a whole also adds to the natural economic sustainability of the latter (Aftab et al., 2024; Badiyal et al., 2024, p. 10). Despite the fact that revegetation or habitat restoration techniques can be initially lucrative, the profitability of the technique would be more appropriate in the long term (a 10-year horizon) than pesticide treatment in the short term (Parry, 2022, p. 1). This economic benefit is further enhanced by the lessened health and environmental expenditure related to lessened contamination and lessened contact with pesticides (Parry, 2022, p. 2). It supports the fact that the initial step towards reaching the win-win outcome on ecological integrity and financial success may be taken with taking into consideration the policy based on biodiversity, aimed at conserving resources (Burra et al., 2021, p. 145887; Parry, 2022). Moreover, the viable use of banker plants (like those introduced in the production of organic strawberries) has demonstrated the potential to apply integrated pest management in an extensive variety of agricultural settings by way of a significant reduction in the extent of individual pest damage (Fenibo & Matambo, 2025, p. 23). This is supplemented by inherent power of biological control plants with less pest resistance than chemical pesticides and thus have a more consistent control over the long-run (Shahini et al., 2023, p. 2085). The ability of some biocontrol agents to choose particular pests without endangering the existence of valuable insects and other non-target species also enables the creation of a balanced agroecosystem, e.g., parasitoids. This demonstrates the fact that the agents are environmentally friendly and selective (Fenibo & Matambo, 2025, p. 6). This selective response can reduce the collateral effects within agro-ecosystems and maintain the complex interactions within the food web to maintain the ecological health over the long-term (Yu et al., 2021, p. 12). Also, the fact that biological control agents are capable of delivering a stable payback to the investment, therefore, making them an alternative to the traditional intervention strategies, that rely on chemical agents, is another financial advantage of their application (Agboka et al., 2023, p. 270). Not only do these actions help to conserve the biodiversity, but they also provide the agricultural systems with sustainability in the long run by preserving such valuable ecosystem functions as soil fertility, and pest control (O'Donnell, 2023, p. 195). The strategies also contribute to the enhancement of more general sustainability goals by decreasing the environmental impact of agriculture and improving the capacity of farming systems to endure external shocks (Ukpoju et al., 2024, p. 387).

CONCLUSION

The reason is that this research was a clear indication that biological control is extremely effective, sustainable and cost effective alternative to the traditional systems of pest control that involve the use of chemicals. The results of the experiment in several field observations indicated clearly that the use of biocontrol agents increased both stability in crop production and decreased significantly the population of insects by a significant margin, and the occurrence of diseases. Regarding biodiversity in agroecosystems and soil health and plant health indicators, biocontrol methods also have fewer adverse effects on the non-target organism, and would improve ecological stability in the long-term. This is a strategy that is consistent in terms of change in pest pressure over time and season conditions by less variability of yields and more resistance of a pest recovery that is seen in biocontrol-controlled plots. In addition, the combined study of quantitative data and qualitative ecological evaluation indicated that biological regulation is helpful to the natural regulation functions of the ecosystem in addition to enhancing agronomic performance. These results provide good arguments in the implementation of biocontrol as one of the fundamental components of integrated pest management systems that reduce the usage of synthetic pesticides, reduce environmental degradation, and address the issue of pesticide resistance and human health risks. Although the acceptance, regulation and awareness are still issues of concern, the entire positive evidence of the study illustrates the immense role that biocontrol could have in the world to provide sustainable production and food security in agriculture. Overall, the findings suggest that biological control techniques can be used more broadly and thus result in an increase in production in the long run without endangering the biodiversity and ecosystem services and hence the means of agricultural progression in the future.

REFERENCES

Abdollahzadeh, G., Sharifzadeh, M. S., Ahmadi-Gorgi, H., & Jahantigh, M. (2025). Transforming farmers behavior: embracing reduced pesticide use under the integrated crop management program. Journal of the Saudi Society of Agricultural Sciences, 24(6).

Aftab, Z., Anjum, T., Akram, W., Bokhari, N. A., Rehman, A., Sharif, S., Rizwana, H., & Munir, B. (2024). Biological Pest Control and Sustainable Agroecosystems. In IntechOpen eBooks. IntechOpen.

Agboka, K., Tonnang, H. E. Z., Muriithi, B., Niassy, S., Ndlela, S., Abdel-Rahman, E. M., Mohamed, S. A., & Ekesi, S. (2023).

Economic impact of a classical biological control program: application to Diachasmimorpha longicaudata against Bactrocera dorsalis fruit fly in Kenya. BioControl, 69(3), 269.

Andreata, M. F. de L., Mian, S., Andrade, G., Bueno, A. de F., Ventura, M. U., Almeida, J. E. M., Ivan, E. A. F., Mosela, M., Simionato, A. S., Robaina, R. R., & Gonçalves, L. S. A. (2025). The current increase and future perspectives of the microbial pesticides market in agriculture: the Brazilian example [Review of The current increase and future perspectives of the microbial pesticides market in agriculture: the Brazilian example]. Frontiers in Microbiology, 16. Frontiers Media.

Badiyal, A., Mahajan, R., Rana, R. S., Sood, R., Walia, A., Rana, T., Manhas, S., & Jayswal, D. K. (2024). Synergizing biotechnology and natural farming: pioneering agricultural sustainability through innovative interventions. Frontiers in Plant Science, 15.

Barka, E. A., Jeandet, P., & Lahlali, R. (2023). The Hidden World within Plants 2.0. Microorganisms, 11(12), 2903.

Baş, B. (2024). Bioprotection by Natural Sources for Sustainable Agriculture. In Physiology. IntechOpen.

Beyari, E. A. (2024). Alternatives to chemical pesticides: the role of microbial biocontrol agents in phytopathogen management: a comprehensive review [Review of Alternatives to chemical pesticides: the role of microbial biocontrol agents in phytopathogen management: a comprehensive review]. Journal of Plant Pathology, 107(1), 291. Springer Science+Business Media.

Burra, D. D., Pretty, J., Neuenschwander, P., Liu, Z., Zhu, Z., & Wyckhuys, K. A. G. (2021). Human health outcomes of a restored ecological balance in African agro-landscapes. The Science of The Total Environment, 775, 145872.

Chaudhary, R., Nawaz, A., Khattak, Z., Butt, M. A., Fouillaud, M., Dufossé, L., Munir, M., Haq, I. ul, & Mukhtar, H. (2024). Microbial Bio-control Agents: A Comprehensive Analysis on Sustainable Pest Management in Agriculture. Journal of Agriculture and Food Research, 101421.

Chi, Y., Yu, C., Feng, M., Shu, K., Zhu, Y., & Shi, W. (2024). Effects of field releases of Neoseiulus barkeri on Megalurothrips usitatus abundance and arthropod diversity. Scientific Reports, 14(1).

Colmenárez, Y. C., & Vásquez, C. (2024). Benefits associated with the implementation of biological control programmes in Latin America. BioControl, 69(3), 303.

Cordero-Bueso, G., Vigentini, I., & Chaves-López, C. (2022). Editorial: Microorganisms and their metabolites as biocontrol agents for sustainable agriculture. Frontiers in Microbiology, 13, 1079016.

Curk, M., & Trdan, S. (2024). Benefiting from Complexity: Exploring Enhanced Biological Control Effectiveness via the Simultaneous Use of Various Methods for Combating Pest Pressure in Agriculture. Agronomy, 14(1), 199.

Daniels, A., Maharaj, G., Ram, M., & Lakenarine, R. (2022). Biological Control Methods for Agricultural Mites: A Review [Review of Biological Control Methods for Agricultural Mites: A Review]. Agricultural Reviews.

Dehbi, I., Achemrk, O., Ezzouggari, R., Jarroudi, M. E., Mokrını, F., Legrifi, I., Belabess, Z., Laasli, S., Mazouz, H., & Lahlali, R. (2023). Beneficial Microorganisms as Bioprotectants against Foliar Diseases of Cereals: A Review [Review of Beneficial Microorganisms as Bioprotectants against Foliar Diseases of Cereals: A Review]. Plants, 12(24), 4162. Multidisciplinary Digital Publishing Institute.

El-Saadony, M. T., Saad, A. M., Soliman, S. M., Salem, H. M., Ahmed, A. I., Mahmood, M., El-Tahan, A. M., Ebrahim, A. A. M., El–Mageed, T. A. A., Negm, S. H., Selim, S., Babalghith, A. O., Elrys, A. S., El-Tarabily, K. A., & AbuQamar, S. F. (2022). Plant growth-promoting microorganisms as biocontrol agents of plant diseases: Mechanisms, challenges and future perspectives [Review of Plant growth-promoting microorganisms as biocontrol agents of plant diseases: Mechanisms, challenges and future perspectives]. Frontiers in Plant Science, 13, 923880. Frontiers Media.

Fenibo, E. O., & Matambo, T. S. (2025). Biopesticides for sustainable agriculture: feasible options for adopting cost-effective strategies. Frontiers in Sustainable Food Systems, 9.

Fergani, Y., Refaei, E. A. E., Faiz, N. M., & Hamama, H. M. (2023). Evaluation of chlorpyrifos and Beauveria bassiana as a strategy in the Egyptian sugar beet fields: impact on Spodoptera littoralis (Boisduval) and its associated predators populations and the sugar beetroot yield. Egyptian Journal of Biological Pest Control, 33(1).

Galli, M., Feldmann, F., Vogler, U., & Kogel, K. (2024). Can biocontrol be the game-changer in integrated pest management? A review of definitions, methods and strategies [Review of Can biocontrol be the game-changer in integrated pest management? A review of definitions, methods and strategies]. Journal of Plant Diseases and Protection, 131(2), 265. Springer Science+Business Media.

Góngora, C. E., & Silva, M. do C. (2024). Sustainable Strategies for the Control of Crop Diseases and Pests to Reduce Pesticides. Agronomy, 14(9), 2158.

Jaiswal, D. K., Gawande, S., Soumia, P. S., Krishna, R., Vaishnav, A., & Ade, A. B. (2022). Biocontrol strategies: an eco-smart tool for integrated pest and diseases management [Review of Biocontrol strategies: an eco-smart tool for integrated pest and diseases management]. BMC Microbiology, 22(1). BioMed Central.

Jensen, B., Jørgensen, H. J. L., Collinge, D. B., Jensen, D. F., Dubey, M., Karlsson, M., Heick, T. M., & Jørgensen, L. N. (2022). Microbial biocontrol agents in IPM strategies : reducing pesticide use in wheat and lowering the risk of fungicide resistance. In Research Portal

Denmark (Issue 211, p. 85). Technical University of Denmark.

Lahlali, R., Ezrari, S., Radouane, N., Kenfaoui, J., Esmaeel, Q., Hamss, H. E., Belabess, Z., & Barka, E. A. (2022). Biological Control of Plant Pathogens: A Global Perspective [Review of Biological Control of Plant Pathogens: A Global Perspective]. Microorganisms, 10(3), 596. Multidisciplinary Digital Publishing Institute.

Llorens, E., & Agustí-Brisach, C. (2022). Biocontrol of Plant Diseases by Means of Antagonist Microorganisms, Biostimulants and Induced Resistance as Alternatives to Chemicals. Plants, 11(24), 3521.

Nagari, M., & Charter, M. (2023). Comparing Insect Predation by Birds and Insects in an Apple Orchard and Neighboring Unmanaged Habitat: Implications for Ecosystem Services. Animals, 13(11), 1785.

Nchu, F. (2024). Sustainable Biological Control of Pests: The Way Forward. Applied Sciences, 14(7), 2669.

Nguyen, H. T., Pham, T. T., Nguyen, P. T., Dinh, N. C. G., Le, M. T., Nguyen, T.-D., NGUYEN, T. T., & Nguyen, V. B. (2025). Microbial biocontrol in agriculture: from mechanistic Understanding to field application. Discover Plants., 2(1).

O'Donnell, P. P. (2023). An Investigation of Farmers' Perspective on Biodiversity and Restoring Native Vegetation on Farms Using the Constructivist Approach to Social Inquiry: A Case Study of Beef and Sheep Farmers in Southeastern Gippsland, Australia. Sociology Mind, 13(4), 193.

Padmakumar, A., Chowdary, P., Eswar, K., Kong, L., Yang, W., Gopalakrishnan, S., Cahill, D. M., & Rengan, A. K. (2023). Bacteria-Premised Nanobiopesticides for the Management of Phytopathogens and Pests. ACS Agricultural Science & Technology, 3(5), 370.

Palazzini, J. M., & Sarrocco, S. (2023). Editorial SI EJPP 2023 (Biocontrol using beneficial fungi and bacteria). European Journal of Plant Pathology, 167(4), 423.

Pålsson, J., Porcel, M., Dekker, T., & Tasin, M. (2021). Attract, reward and disrupt: responses of pests and natural enemies to combinations of habitat manipulation and semiochemicals in organic apple. Journal of Pest Science, 95(2), 619.

Parry, H. (2022). Economic benefits of conservation biocontrol: A spatially explicit bioeconomic model for insect pest management in agricultural landscapes. Frontiers in Ecology and Evolution, 10.

Pobożniak, M., & Olczyk, M. (2025). Biocontrol in Integrated Pest Management in Fruit and Vegetable Field Production. Horticulturae, 11(5), 522.

Ratto, F., Bruce, T. J. A., Chipabika, G., Mwamakamba, S., Mkandawire, R., Khan, Z. R., Mkindi, A. G., Pittchar, J., Sallu, S. M., Whitfield, S., Wilson, K., & Sait, S. M. (2022). Biological control interventions reduce pest abundance and crop damage while maintaining natural enemies in sub-Saharan Africa: a meta-analysis [Review of Biological control interventions reduce pest abundance and crop damage while maintaining natural enemies in sub-

Saharan Africa: a meta-analysis]. Proceedings of the Royal Society B Biological Sciences, 289(1988). Royal Society.

Rayalu, M. B., & Anuradha, S. (2024). The intersection of ecology and agriculture: Biological control as a tool for pest management. International Journal of Plant Pathology and Microbiology, 4(2), 46.

Riojá, T. (2022). Control biológico en agroecosistemas de zonas áridas de Chile. Idesia, 40(3), 3.

Shahini, S., Mustafaj, S., Sula, U., Shahini, E., Skura, E., & Sallaku, F. (2023). Biological Control of Greenhouse whitefly Trialeurodes vaporariorum with Encarsia formosa: Special Case Developed in Albania. Evergreen, 10(4), 2084.

Shaili, S. J., Kabiraj, U. K., & Mahedi, M. (2025). Fungal Biocontrol in Agriculture: A Sustainable Alternative to Chemical Pesticides – A Comprehensive Review [Review of Fungal Biocontrol in Agriculture: A Sustainable Alternative to Chemical Pesticides – A Comprehensive Review]. World Journal of Advanced Research and Reviews, 26(1), 2305. GSC Online Press.

Ukpoju, E. A., Adefemi, A., Adegbite, A. O., Balogun, O. D., Obaedo, B. O., & Abatan, A. (2024). A review of sustainable environmental practices and their impact on U. S. economic sustainability [Review of A review of sustainable environmental practices and their impact on U. S. economic sustainability]. World Journal of Advanced Research and Reviews, 21(1), 384. GSC Online Press.

Ullah, N., Bari, T., Ali, A., Fatima, H., Lodhi, S. S., Noureen, A., & Munir, I. (2023). Role of Biopestcides and Biofertilizer in Sustainable Agriculture. Journal of Survey in Fisheries Sciences, 10(3), 156.

Upadhyay, A., Hadiya, J., & Gharde, S. (2021). Biocontrol: An effective tool for agricultural insect pests management. The Pharma Innovation, 10, 284.

Villavicencio-Vásquez, M., Espinoza, F., Espinoza-Lozano, L., & Coronel-León, J. (2025). Biological control agents: mechanisms of action, selection, formulation and challenges in agriculture. Frontiers in Agronomy, 7.

Yousefi, M., Marja, R., Barmettler, E., Six, J., Dray, A., & Ghazoul, J. (2024). The effectiveness of intercropping and agri-environmental schemes on ecosystem service of biological pest control: a meta-analysis. Agronomy for Sustainable Development, 44(2).

Youssef, A. S. B. (2023). Modern trends for the application of biological control and modern technologies in agricultural projects. Deleted Journal, 0.

Yu, Y., Yang, H. L., Lin, Z., Yang, S., Zhang, L.-W., Gu, X., Li, C., & Wang, X. (2021). Development and Area-Wide Application of Biological Control using the Parasitoid Aphidius gifuensis Against Myzus persicae in China. In CRC Press eBooks (p. 3). Informa.