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Hestia to Demeter: Reducing Agrochemical Pollution to Empower Women Farmers

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Abstract. The 2020 Farm to Fork strategy by the European Commission aimed to reduce agrochemical pollutants and protect biodiversity but stirred controversy due to conflicts between intensive agriculture demands and environmental priorities. Strict limits on agrochemical residues required farmers to produce less. The de-intensification and agroecology prone policy impacted livelihoods, sparking political upheaval. Due to lack of pesticide alternatives and extension services, Lebanese exports have faced challenges complying with residue restrictions. Agricultural laborers and consumers are exposed to high levels of pesticide residue. Undocumented refugee women form a significant part of the agricultural workforce, and women led agricultural cooperatives have minimal access to funding, exacerbating gender inequity. The American University of Beirut (AUB) has played a pivotal role in agroecology research, rural development, and gender equity. Knowledge transfer promotes civic awareness and private sector partnerships. Local Natural enemies and parasites emerged as a residue-free alternative to agrochemicals. Biocontrol-based integrated pest management holds great potential for mitigating pesticides hazards to human and environmental health. Launching the "natural predators" initiative from women-run farms holds a great promise in dually resolving the problems of agrochemical pollution and gender equity in the agricultural sector. Empowering women in agriculture aims to transform their role from care work to farm management. This paper focuses on the technical aspects of developing "natural enemies" as pesticides alternative for Lebanese agriculture, aiming to overcome export challenges and revitalize the economy. "Farm to Fork meets Hestia to Demeter" underscores AUB's commitment to sustainability aligns climate action with gender equity. By supporting women entrepreneurs and addressing climate change's impact on public health, the initiative contributes to AUB's broader mission of advancing Lebanon and the region through Education for Sustainable Development.

Keyword:
Women empowerment, Agricultural sustainability, biological control, gender equity.

1. Introduction

Women's empowerment stands as a global critical issue, particularly in the MENA region, where gender disparities continue to persist despite the historical engagement of civil society and ample advances in policy (Avis 2017, Mocbil 2022, Monqid 2024). Across various sectors, including agriculture, women face barriers that hinder their full participation and leadership (Naguib 2024). Through a diverse approach encompassing research, education, and community engagement, the American University of Beirut (AUB)'s dedication to sustainability aligns climate action with gender equity, food safety, and food security, particularly in regions plagued by socio-economic and environmental challenges.

The question of sustainable livelihoods in the Lebanese agricultural sector is confounded by decades of mismanagement, especially when it comes to the gender equity component (Hamade, Malorgio et al. 2015). The informal employment setup in Lebanese agriculture has always been the law of the land. Early studies highlighted the alarming tendency of making the export of typical Lebanese crops (citrus and apples) the focus of agricultural economy, and relying on importation for critical food items. Such an approach depended on world market trends and expose national food security to unpredictable risks (Nasr 1978). Today, peculiarly enough, the contribution of the agricultural sector to the national GDP is less than 3.5%, same as the sector's total bank credits in 1973, calculated with the price inflation following the multiple crises compounding the area (Khafagy, Díaz-González et al. 2022). Relying on wage labor, instead of strengthening agricultural technologies, exacerbates the risks world of market fluctuation on primary agrarian items. The state budget for agriculture in 1973 was 2.3%, and less than 1% today. Further compounding our understanding is the lack of statistical data (Sakr 2022). The Lebanese government never invested in the sector through agricultural subsidies, crop insurance, or safety nets, letting the free-market shape it. Geopolitical backdrops like the refugee status of wage laborers, and its effect on labor legislation further complicate its understanding (Noory, Habib et al. 2024). Therefore, we opted to limit our approach to a specific problem, and an actionable solution, even though the cyclic historicity may give the impression of an inescapable repetition. The aim here is to empower women inside the household as well as outside, and transform their role from managing the kitchen, to running the farm and the food production. The title is meant to invoke that transition form the realm of Hestia, the goddess of the fireside and cooking, to Demeter, agriculture's divine protector.

In the context of food production, empowering women entails not only providing them with equal access to resources and opportunities but also ensuring their safety and well-being in the workplace, and addressing the gaps through a feminist informed approach, which was formulated into the methodology (Farhall and Rickards 2021). For too long, women farmers have been subject to environmental and health risks associated with high exposure to pesticide use and residues (London et al., 2002). According to literature, the three major pathways of pesticide entry into a farmer's body include inhalation, ingestion, and dermal absorption. Women, being one of the most vulnerable populations, are particularly at risk of these health hazards (Martin-Reina et al., 2021). More importantly, women make up the bulk of the workforce in greenhouse crops. Undocumented refugee women form a significant part of the agricultural workforce, and women led agricultural cooperatives have minimal access to funding, exacerbating gender inequity (Hejase, Hamie et al., Abdelali-Martini and Dey de Pryck 2015).

Biological control of arthropod pests in greenhouse crops has a long history of success and it is becoming increasingly prominent as growers seek to mitigate the impacts of high reliance on pesticides (Gonzalez et al., 2016; Pilkington et al., 2010). The use of biological agents has gained traction, showcasing a sustainable alternative to conventional chemical pesticides. Over the years, multiple bio-control agents such as predatory mites and entomopathogens, have played a significant role in the market growth of biocontrol agents, demonstrating high efficacy against serious arthropod pests.

In this paper, we aim to test the efficacy of the local fungus *Beauveria pseudobassiana* and locally collected predatory mites *Amblyseius swirskii* and *Phytoseiulus persimilis* for the integrated pest management (IPM) of major tomato and cucumber pests under commercial greenhouse conditions. Our research findings indicate that the integration of these biocontrol agents in greenhouse environments is highly effective, significantly reducing the need for pesticide application. These results highlight the significance of biological control in providing sustainable pest management solutions in the agricultural sector. Additionally, it empowers women farmers with effective tools to protect their crops and livelihoods while promoting environmental sustainability and resilience of agricultural systems.

Through these efforts, AUB advocates and actively contributes to the empowerment of women in agriculture by promoting safer, healthier, and more equitable working conditions. This approach supports the physical health of women in agriculture and boosts their economic independence and social status, thereby fostering broader socio- economic development. By integrating these sustainable practices, we can ensure a more resilient and sustainable agricultural sector that protects and supports women and contributes to the overall prosperity of communities in the Mediterranean region.

2. Methodology

2.1. Field Evaluation of the efficacy of the local fungus *Beauveria pseudobassiana* predatory mites *Amblyseius swirskii* and *Phytoseiulus persimilis* for the management of greenhouse cucumber pests

2.1.1. Field location

A large-scale commercial size greenhouse trial was conducted in Rmeileh, South Lebanon, from September to December 2023 on cucumber plants. The trial comprised three traditional arched tunnel greenhouses, each covering an area of 325 m² (7x46.5m). Within each greenhouse, eight rows were cultivated, accommodating approximately 900 to 1000 cucumber plants. One greenhouse functioned as a control, following strictly conventional agricultural practices, while the other two employed innovative bio-Integrated Pest Management (BIPM) measures. The first IPM greenhouse (IPM-A) primarily relied on *B. pseudobassiana*. while the second greenhouse (BIPM-B) utilized predatory mites *P. persimilis* and A*. swirskii*. A drip irrigation system was installed, ensuring precise and adequate crop hydration. Cucumber seedlings were transplanted with on September 11th spaced at a density of 2 plants/m².

2.1.2. Bio-control agents, Pre-transplanting Measures, and Post-transplanting Measures

A local strain of *B. pseudobassiana* was cultured on potato dextrose agar and formulated to a concentration of 108 spores/mL for field application. A conidial formulation of 108 conidia mL-1 + 0.01% Tween 20 + 1% corn oil was used. The fungal formulation was sprayed based on pest scouting results. A uniform spray coverage of plants was achieved using a 20L battery operated knapsack sprayer (Montana®).

The local strain of *A. swirskii* was collected from castor plants from Batroun area, North Lebanon. The mite was reared at the AUB laboratory in controlled environment growth cabinets using a specially developed rearing method.

The local strain of *P. persimilis* was collected from bean plants from Jiyeh, South

Lebanon. The mite was reared at the AUB laboratory on bean plants infested with *T. urticae*.

Soil solarization was conducted, and all greenhouses were equipped with clear plastic polyethylene covers and insect-proof nets covering the vents. Weeds and plant debris from previous seasons were manually removed without the use of herbicides. Yellow sticky traps (YSCs) and blue sticky traps (BSCs), kindly provided by the Ministry of Agriculture extension service, were deployed to capture whiteflies and thrips. Trap plants (blossomed marigolds and beans) were introduced and replaced before transplanting to remove any pests attracted to them. Daily temperature and humidity were recorded using Data loggers (Ebro®).

In the control greenhouse, the same pre-transplanting procedures were followed excluding the introduction of trap plants, and yellow/blue sticky traps. All cultural practices, except for pesticide sprays, were similar in the three treatments.

Plants were left under natural pest infestations. Weekly scouting for insects/mites and predators was conducted by women agriculture engineers, who also provided training to women workers on scouting techniques and the application of biocontrol agents as needed. Scouting involved the inspection of five randomly selected cucumber plants per row, totaling 40 plants per greenhouse. Three leaves from the upper, middle, and lower parts of each plant were examined, resulting in a total of 120 leaves per greenhouse. Populations of adult and immature stages of arthropod pests; whiteflies, spider mites and thrips were recorded and the average of each was calculated. The same monitoring framework was performed for *P. persimilis* and *A. swirskii*. During the season, five spraysof B. pseudobassiana were applied in the BIPM greenhouse (BIPM-A) whereas four introductions of *A. swirskii* were carried out at a release rate of 25 mites/ m2 in the beginning of the season (1st and 2nd releases) and increased with the growth of cucumber plants to 50 mites/m2.Three releases of P. persimilis were performed in hotspots due to the non-uniform spread of *T. urticae* populations.

2.1.3. Statistical Analysis

The collected data was analyzed using the statistical package for social sciences (SPSS 25 for Windows). Descriptive statistics were presented to summarize the study variables of interest as counts and percentages for the categorical variables and as means and standard deviations for the continuous ones. A two-way ANOVA (Analysis of Variance) was performed to assess the effects of the two variables (protection method, and time) and their interactions on the plant health of plants. This was followed by testing for statistically significant differences between variables based on Bonferroni's test used to address multiple comparisons. All reported p-values were based on two-sided tests and were compared with a significance level of 5%.

3. Results

3.1. Environmental conditions

Temperature and Relative Humidity (RH) variations were recorded throughout the cucumber trial conducted from September to December 2019. Mean daily temperatures ranged from 31.281°C in week 2 to 19.08°C in week 10, with minimum and maximum mean temperatures recorded at 15°C and 32°C, respectively. Average RH fluctuated between 51% and 90%.

3.2. Control of whiteflies on cucumber

In the control greenhouse, six insecticidal sprays were applied during the growing period, but they failed to effectively control whitefly populations, which surpassed economic threshold levels (ET) by mid-November. Despite initial low whitefly numbers, the population steadily increased, reaching a peak of 4.12 adults/leaf and 19.7 nymphs/leaf by the end of the experiment (Fig. 1&2). The inefficiency of the applied chemicals might be linked to different factors including wrong application methods, rate or timing of sprays, insufficient leaf coverage, but mostly to whitefly tolerance to abamectin and acetamiprid which have been repeatedly used without alterations.

In the BIPM-A greenhouse, five *Beauveria* sprays effectively controlled whiteflies, keeping populations below ET throughout the season. Whitefly adult populations remained consistently low, averaging below 1 adult/leaf, while nymph densities peaked at 2.57 nymphs/leaf and declined progressively thereafter. Parasitized whitefly nymphs due to fungal infection were observed. In the BIPM-B greenhouse, *A. swirskii* releases successfully maintained whitefly populations below ETL. Despite early high temperatures, *A. swirskii* activity remained effective, and maintained low whitefly populations. Additional releases of *A. swirskii* were carried throughout the trial, resulting in a significant reduction in whitefly populations by the end of the experiment. There was a significant difference in the average number of whitefly adults and nymphs between treatments ($P < 0.05$). Compared to the control, both BIPM strategies led to substantial reductions in whitefly populations, with BIPM-B showing slightly better efficacy than BIPM-A. Relatively, the average adult population was significantly lower in BIPM-A by

94.6 % and in BIPM-B by 94 % as compared to the pesticide control. A similar pattern persisted among the nymphal population but at higher densities compared to adults. Onthe last week, the average number of nymphs reached 19.71, 1.06 and 1.2 nymphs/leaf in the control, BIPM-A and BIPM-B greenhouses, respectively. (Fig.2).

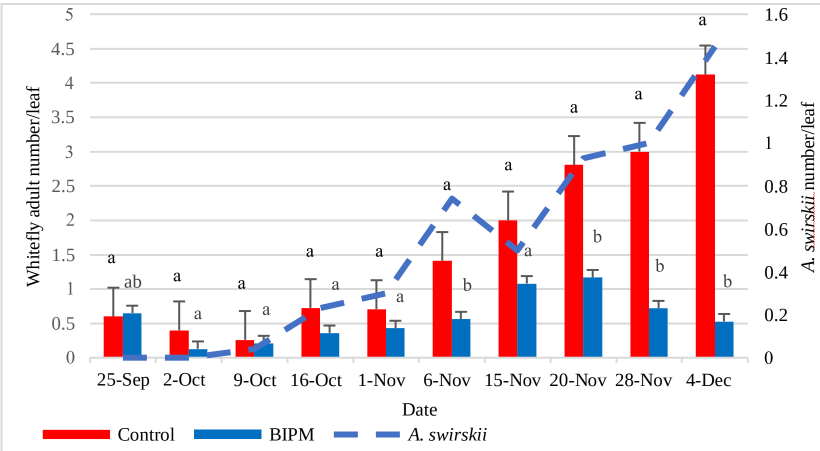

Figure 1. Average whitefly adults and A. swirskii on cucumber leaves in the control and BIPM tunnels. Different letters (a andb) indicate statistically significant differences in the pest numbers when comparisons are made between the two treatments within the same week

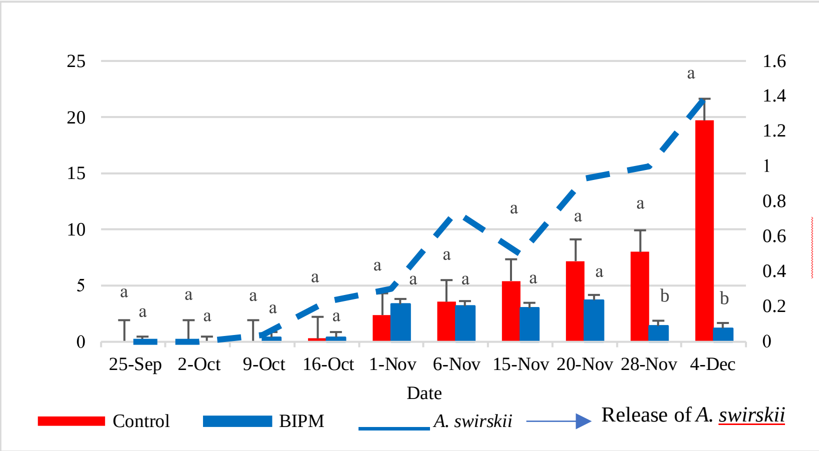

Figure 2. Average whitefly nymphs and A. swirskii on cucumber leaves in the control and BIPM tunnels. Different letters (a and b) indicate statistically significant differences inthe pest numbers when comparisons are made between the two treatments within the same week

3.3 Control of thrips on cucumber

In the control greenhouse, thrips were almost absent throughout the growing season (Fig. 3). The applied insecticides were able to suppress thrips population. Similarly, in BIPM-A greenhouse, the thrips population was almost negligible. The application of five *Beauveria* sprays during the cucumber season maintained the average number of thrips below the ET level of 1.3 thrips/leaf (Fig. 3). In BIPM-B greenhouse, *A. swirskii* provided sufficient control against thrips population and maintained it below the ET throughout the growing period. Despite a slight increase in thrips numbers during the first half of November, subsequent releases at rates of 25 and 50 mites/m2 kept populations below ET, with a peak of 1.45 mites/leaf recorded in December 4th. There was a significant difference in the average number of thrips between treatments (p = 0.000), weeks (p = 0.000) as well as treatment*week (p = 0.000). Throughout the season, the thrips population was suppressed and maintained below ET in all the three greenhouses. The use of *Beauveria* was almost statistically equivalent to chemical insecticides in reducing thrips population. As for *A. swirskii*, the thrips population was slightly higher than the latter two yet below the ET.

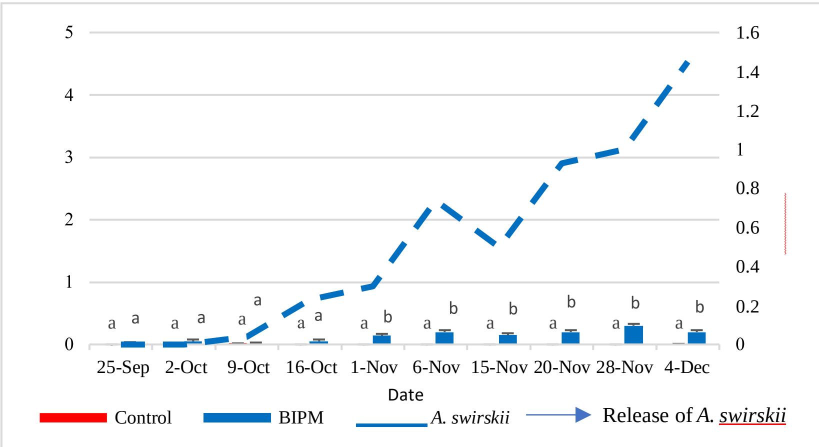

Figure 3. Average thrips and *A. swirskii* on cucumber leaves in thecontrol and BIPM tunnels. Different letters (a and b) indicate statistically significant differences in the pest numbers when comparisons are made between the two treatments within the same week.

3.4. Control of spider mites on cucumber

In the control greenhouse, the spider mite population remained below ET of 2 mites per leafuntil the beginning of November. However, it rapidly increased thereafter, reaching an average of 19.72 mites per leaf by the end of November and peaking at 40.17 mites per leaf by the end of the experiment (Fig. 4). Despite the application of three insecticidal sprays containing abamectin, acetamiprid, and lambda-Cyhalothrin during this period, the population continued to escalate. In BIPM-A greenhouse, five *Beauveria* sprays effectively suppressed the spider mite population, maintaining it below 1 mite per leaf throughout the experiment, except for two peaks recorded during mid-October (Fig. 4).

In BIPM-B greenhouse, hotspot releases of *P. persimilis* effectively controlled spider mites. However, an initial outbreak occurred during mid-October, prompting two hot spot treatments of *Phytoseiulus* at a rate of 12 mite/m2. An additional hotspot treatment was done on November 1st, covering a wider greenhouse area. This facilitated the establishment of *Phytoseiulus*, which peaked at 2.5 mites per leaf, leading to a gradual decrease in the spider mite population below the economic threshold level after three weeks. By the end of the season, spider mite numbers were negligible, with the population of *Phytoseiulus* declining in the absence of prey as a food source. The spider mite population was almost negligible in BIPM-A and IPM-B exhibiting a significantly lower count as compared to the control group, which reached 40 TSSM/leaf on December 4 (p = 0.000).

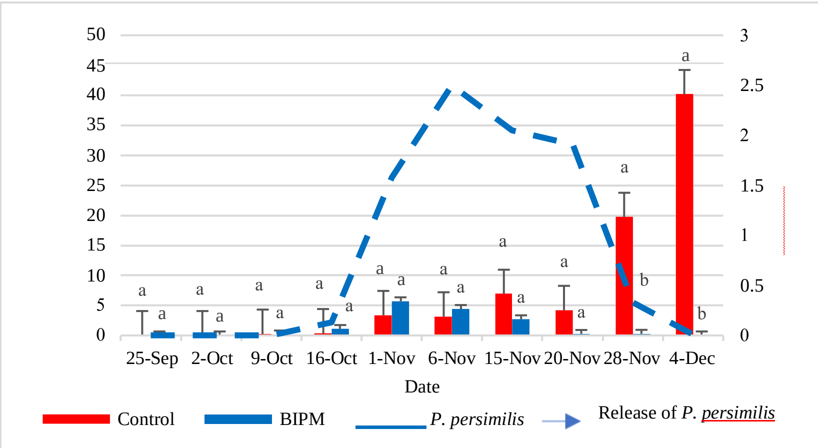

Figure 4. Average two-spotted spider mites (TSSM) and *P. persimilis* on cucumber leaves in the control and BIPM tunnels. Different letters (a and b) indicate statistically significant differences in the pest numbers when comparisons are madebetween the two treatments (Control vs BIPM) within the

4. Discussion

4.1. Greenhouse production and pest control

Greenhouse production in Lebanon and many neighboring countries rely mostly on women as workface. Women perform the daily activities including pruning old leave, training the plants, removing suckers or side branches, attaching plants to the strings/crop holders, and harvesting, spending over 4-6 hours daily inside greenhouses. When pesticides are applied, the pesticide applicators, mostly men, are exposed to the pesticides sprays mainly during the application process, while women are exposed daily for several hours through contact or through inhalation. This constitutes a significant health hazard, especially that the re-entry interval (the time immediately after a pesticide application when entry into the treated area is restricted) is not observed or enforced. In addition, women workers and their children consume the fruits and vegetables produced in their workplace, increasing the health risks through oral exposure to pesticide residues. The acute (direct toxicity within a short period) and chronic health hazards (cancer, mutations, reprotoxic effects, neurological disorders, endocrine disruption, etc.) are well documented.

The region adopting biological alternatives to conventional chemical control is therefore a categorial imperative. Entomopathogenic fungi (EPFs) and predatory mites are among the most important biological agents and their use is globally increasing. Intensive studies on EPFs, mainly *Beauveria* spp., proved its equivalence to or even superior than chemical pesticides in controlling some commercially damaging pests. Likewise, multiple success stories and field trials have been associated with the use of predatory mites *A. swirskii* and *P. persimilis*.

4.2 Biological Control of Whiteflies, Thrips, and Spider Mites

Previous studies have demonstrated the efficacy of *A swirskii* in controlling whitefly populations on cucumbers in field conditions (Messelink et al., 2005; Calvo et al. 2012). Nomikou et al., (2001) observed a dramatic decrease in *Bemisia tabaci* populations, noting a reduction of 16 to 21 times following the release of *A. swirskii* compared to untreated controls. Our study showed similar results, by which *A. swirskii* exhibited the ability to thriveand establish at elevated temperatures, suggesting a thermotolerant characteristic of the local A. swirskii strain. Our observations during a period of high temperatures, ranging from 41 to 54°C in the initial five weeks and stabilizing between 40 to 45°C towards the end of November, underline the importance of assessing the thermal limits of local biocontrol agents. Given these conditions, our study recommends precise and consistent monitoring of pest populations during warmer periods, with weekly releases of *A. swirskii* at specific ensuring effective control and prevention of pest outbreaks. To further enhance the effectiveness of these measures, it is essential to provide specialized training for women in these monitoring techniques.

The role of *B. bassiana* in managing whitefly populations was significant. The application of five fungal sprays in our greenhouse trials on cucumbers resulted in substantial reductions in adult and nymphal populations of *B. tabaci*. These results align with findings from other studies on commercial strains of *B. bassiana*, which showed similar control efficacy under laboratory conditions, achieving an 81.1% mortality rate against *B. tabaci* compared to 8.8% in the control group (Bugti et al. 2018). Field studies also reinforce the potency of *B. bassiana*,with Abdel-Raheem & Al-Keridis (2017) reporting over 90% mortality in *B. tabaci* adults.

The suppression of thrips by *A. swirskii* has been well documented in both cucumber and sweet pepper crops under laboratory and greenhouse conditions (Messelink et al., 2008, Nomikou et al., 2010). We found that four releases of *A. swirskii* were sufficient to control both whitefly and thrips populations, without any chemical intervention.

The local strain of *B. pseudobassiana* also demonstrated effectiveness in suppressing thrips populations, offering control comparable to chemical pesticides. Our greenhouse trials further demonstrated that oil-based formulations of the fungi were effective against *F. occidentalis*, as well as at temperatures exceeding 40°C throughout most of the growing season.

Our research confirmed the high efficacy of *P. persimilis* in controlling populations of the two-spotted spider mite on cucumber plants. In the control setting, the spider mite populations exceeded the ET while in the IPM-treated greenhouse, the presence of *P. persimilis* kept spider mite populations below the ET for most of the season. The predatory activity of *P. persimilis* is well-supported by literature, showing effectiveness in both open field andgreenhouse crops (Opit et al., 2004; Ullah and Lim, 2017; Yanar et al., 2019).

The local strain of *B. pseudobassiana* demonstrated high virulence against *T. urticae* under commercial greenhouse conditions. The effectiveness of different Beauveria bassiana isolates (1 × 10^8 spore/mL) against TSSM has been reported in laboratory, small-scale experiments and field trials (Shin et al., 2017; Yucel et al., 2021).

4.3. Implications on Women Empowerment in Agriculture

4.3.1. Enhancing Leadership Through Skill Enhancement and Decision-Making

The empowerment of women through training in using biological pest control methods represents asignificant shift towards enhancing their agency and leadership within the agricultural sector. This approach significantly mitigates health risks associated with chemical pesticide exposure, especially in regions where women are a major part of the agricultural workforce. As highlightedin the study from West Bengal by Shamna (2022) the use of technological interventions promotes increased activity in farming operations and fosters leadership skills. They gain more authority, favoring a shift in traditional perceptions and roles within their communities. The evolution of gender streamlining in agriculture, ushers more sustainable and equitable farming practices. By enabling women to lead paves the way for a more inclusive and resilient agricultural sector.

By training women to become decision-makers in the agricultural sector, they gain a higher social standing and contribute more effectively to community development and economic growth. The implementation of biological control techniques often requires carefulmonitoring and management of pest and predator populations. The acquired skills enhance the farmers' job quality by engaging them in roles that require critical thinking and planning rather than just manual labor.

4.3.2. Socio-Economic Benefits and Improved Livelihoods and Market Access

The socio-economic uplift of women through the adoption of biological control methods also contributes to broader community well-being. Women's involvement in agriculture is substantial, and their empowerment leads to improved community resilience and economic stability. The paper stresses that agricultural development through women's empowerment results in enhanced agricultural productivity and household food security. The use of bio- intensive integrated pest management (BIPM) methods not only provides an effective alternative to chemical pesticides but also promotes the production of higher-quality crops. This can lead to better marketability and the potential for premium pricing, improving the economic returns for farmers, particularly women, who often manage household finances. Furthermore, as women gain more income and control over financial resources, they invest more in their families and communities, contributing to a cycle of poverty reduction and enhanced societal benefits. Empowering women in agriculture extends beyond productivity improvements; it significantly impacts their economic status and market engagement. When women are trained in modern agricultural techniques and business skills, they gain vital insights into market dynamics, which helps them to access new markets and negotiate better terms for their products. This training includes understanding the value chains, identifying potential buyers, and leveraging digital platforms for marketing their products. According to a study by Maertens and Swinnen (2012), involving women in high-value agriculture through training and cooperative memberships significantly increases their income levels, as they participate more actively in the markets. Furthermore, the FAO notes that when women receive equal access to resources and markets, farm yields can increase by 20-30%, raising total agricultural outputs in developing countries by 2.5-4%, which can significantly reduce hunger globally.

4.3.3. Policy Recommendations and Future Directions: The Specific Case of Lebanon.

To further support women's empowerment through agriculture, policy makers should focus on increasing access to education, resources, and technologies that facilitate sustainable practices. Awareness campaigns targeting farmers, consumers, and decision-makers can helpshift perspectives towards more gender-inclusive policies and practices.

Continued investment in technologies that reduce labor intensity and improve safety iscrucial. Providing women with access to these technologies improves theirproductivity and their overall health and well-being. This approach aligns with global efforts to achieve gender equality and sustainable agriculture, emphasizing the need forpolicies that specifically address the challenges and opportunities for women in agriculture. Lebanon’s total arable land area reached 13.6% in 2021, while the agricultural sector employsaround 12.1 of the total labor forces, of which less than 9% are documented. The Lebanese farming sector’s totaldebt was around $80 million in 2019 (Dal, Díaz-González et al. 2021). Exports to neighboring Gulf countries and European niche markets are therefore an indispensable helpline that thesector requires for a likely redress. Many mitigation approaches have been adopted to enhance the resilience of these farms. As an example, diversified farming with olive trees have been incorporated into gardening and perennial crop farms to improve their resilience to drought. This method mitigates water shortage conditions, a common risk in semi-arid regions like Lebanon. Yet, the overuse of agrochemicals is causing the gains to dissipate and adds pollution to the burdens of climate change (Darwich and Madau 2024). Reducing pesticide use and providing equitable skill acquisition favor gender streamlining in the agricultural sector. With proper planning andcustomized extension protocols, the policy will significantly reduce the burden of debt and the lack of skilled labor.

5. Conclusion

In conclusion, the findings of this study highlight the essential role of women empowerment in agricultural practices, particularly in the context of Biointensive Integrated Pest Management (BIPM). Our study demonstrates that employing natural enemies for cucumbergreenhouse pest control can yield comparable, if not superior, results to traditional pesticide methods. This not only emphasizes the efficacy of BIPM but also shows its potential in transforming farming practices.

By being trained on BIPM practices, women farmers are equipped with effective tools for pest management and afforded greater autonomy and decision-making power over their farming operations. This empowerment extends beyond the confines of pest control, fostering a sense of leadership among women in agriculture. Moreover, the benefits of BIPM outweigh any required additional expenses. BIPM presents profitable export opportunities by enhancing the quality of vegetables produced. Specifically, in Lebanon, adopting BIPM can significantly reduce pesticide residues in produce, aligning with strict international standards and expanding market access. Through BIPM, can command premium prices in international markets, thereby enhancing their income and overall well-being. This economic empowerment serves as a catalyst for socioeconomic development, reducing Lebanese farmers' poverty and contributing to the prosperityof their communities.

Extending these benefits on a broader scale through targeted awareness campaigns aimed at farmers, consumers, and policymakers, particularly in developing countries, is effective. These efforts emphasize the long-term advantages of BIPM over the immediate savings from conventional pesticides, highlighting the health, environmental, and economic gains. By promoting BIPM, we advocate for a sustainable agricultural practice that not only enhances productivity but also supports economic and social empowerment. By investing in BIPM, stakeholders can create a more resilient and sustainable agricultural system that empowers farmers and ensures food security for generations to come. While it is acknowledged that BIPM may entail slightly higher costs initially, the associated health and economic advantages make it a valuable investment for the future of agriculture, particularly in empowering women farmers to grow.

By prioritizing gender mainstreaming initiatives in agricultural policies and extension programs, Lebanon can empower women farmers and laborers to play a more active role in agricultural decision-making processes. This can involve providing tailored training programs, access to financial resources, and opportunities for leadership and skill development. Moreover, incorporating gender-sensitive approaches into agricultural practices can lead to more sustainable and inclusive outcomes, benefiting both women and the agricultural sectoras a whole. By embracing gender streamlining in agriculture, Lebanon can foster a more equitable and resilient agricultural landscape, where women are valued participants and contributors to agricultural development. This not only enhances the sector's overall productivity and sustainability but also promotes social justice and gender equality within Lebanon's rural communities.

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