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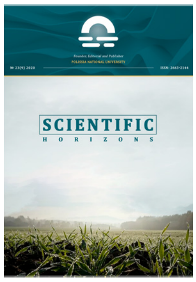

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Organic raspberry cultivation in Lviv region

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Abstract. The purpose of this study was to establish scientifically based approaches to the use of biological methods of raspberry protection to increase both yield and quality in organic farming. The study investigated the effectiveness of biological means of protecting raspberries from the main pests, specifically aphids (*Aphis ruborum*), caterpillars, and raspberry beetle (*Byturus tomentosus*), in the field conditions of Lviv region. Three types of biological agents were used for the experiment: entomophages (ladybugs, trichogramma) and bioinsecticides based on *Bacillus thuringiensis*. The experimental design included a control group without protection, groups with the use

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of individual agents, and a combined group where all methods were used simultaneously. The count of pests and the level of fruit damage were analysed on a decadal basis during the growing season, which lasted from May to August. The findings revealed that the combined use of biological agents was the most effective. The use of ladybugs reduced the count of aphids by 85%, trichogramma reduced fruit damage by caterpillars by 90%, while bioinsecticides reduced yield losses caused by raspberry beetles by 60%. In the combined group, the count of pests decreased by up to 98%, while yield losses were reduced to a minimum. The economic analysis confirmed the feasibility of using biological methods: the combined approach increased the profitability of raspberry cultivation by 35% while ensuring that the products met organic farming standards. The findings of the study demonstrated the high efficiency of biological pest control agents, their economic viability, and environmental safety. The findings are of practical significance for organic farming and can be used as recommendations for farmers

Keywords: agriculture; biological products; pests; biological protection; entomophages

INTRODUCTION

Raspberry cultivation is a significant segment of agriculture in Ukraine, specifically in the Lviv region, which is characterised by favourable climatic and soil conditions for this crop. The relevance of the subject under study lies in the necessity of ensuring effective protection of raspberry plantations from pests, while maintaining environmental safety and compliance with organic standards. The growing demand for raspberries grown according to organic farming principles dictates the requirements for environmentally friendly pest control methods that not only reduce crop losses but also maintain the natural balance in agroecosystems. Despite their effectiveness, traditional chemical pest control products are increasingly being replaced due to the risk of environmental pollution, accumulation of toxic substances in products and negative impact on beneficial insects and biodiversity (Shahini *et al.*, 2024).

One of the key challenges in raspberry cultivation is the vulnerability to major pests such aphids (*Aphis ruborum*), caterpillars, and the raspberry beetle (*Byturus tomentosus*) (Sykalo & Shpak, 2024). These pests cause extensive damage to the crop by damaging leaves, shoots, and fruits, resulting in a 30-50% reduction in yield depending on the level of infestation. Conventional control methods, including the use of chemical pesticides, albeit effective, pose environmental risks, degrade product quality, and contradict organic farming standards (Haleeva *et al.*, 2024). At the same time, inaction in pest control is unacceptable due to possible crop losses and reduced economic stability of farms (Maharramova, 2023). The introduction of biological methods of protection, such as entomophages (ladybugs, trichogramma) and bioinsecticides, is intended to solve this problem, but their effective impact and economic feasibility require in-depth scientific analysis and field research.

The problem of the effects of protection and fertilisation systems on raspberry quality continues to be a key issue in organic farming. M. Balawejder *et al.* (2022) demonstrated that changing the substrate in soilless raspberry cultivation can increase the content of bioactive substances in the fruit. However, the researchers did not investigate the effects of biological plant protection products on quality and yield in the field. R. Anjos *et al.* (2020) confirmed that organic methods of raspberry cultivation contribute to the preservation of the phytochemical composition of berries compared to conventional systems. However, the study did not factor in the effects of entomophages on the biochemical composition of the fruit. S. Murtić *et al.* (2022) compared the quality of raspberry fruit of Meeker variety from organic and conventional cultivation systems, emphasising the advantages of organic systems. However, the study was focused on berry quality, without emphasis on pest management practices.

D. Sangiorgio *et al.* (2021) found that organic farming increases the flavour and biodiversity of beneficial bacteria on raspberries. However, the effects of biological agents on long-term pest control and interaction with microflora were not analysed. M. Kotuła *et al.* (2022) characterised the chemical composition of raspberries from organic, conventional, and wild cultivation. The researchers emphasised the significance of organic systems, but did not consider biosecurity measures. A. Ponder and E. Hallmann (2020) studied the vitamin C content of different raspberry varieties from organic and conventional cultivation systems. The data highlighted the benefits of the organic approach but leave open questions about the influence of biological pest control methods. M. Milinković *et al.* (2021) investigated the chemical composition of the Willamette variety raspberry fruits grown in different systems. The researchers confirmed the environmental benefits of the organic approach, but did not consider the cost-effectiveness of the protection products. M.N. Frías-Moreno *et al.* (2021) focused on the antioxidant activity of raspberries depending on fertiliser. However, the study did not analyse biological pest control agents. A. Estrada-Beltran *et al.* (2020) discovered the effect of organic fertilisers on volatile compounds in raspberry fruit. However, their research did not cover aspects related to pests and control methods. A. Ispiryan *et al.* (2023) emphasised the role of sustainability in raspberry cultivation. The researchers covered a wide range of issues, but did not consider the effects of biological control agents on berry yield and quality.

The analysis of these sources showed that although many studies examined organic raspberry cultivation systems, the use of biological control agents and their effectiveness, economic feasibility, and interaction with other factors are still understudied. The purpose of the present study was to evaluate the effectiveness of biological control agents, such as entomophages (ladybugs, trichogramma) and bioinsecticides based on *Bacillus thuringiensis*, in the control of major raspberry pests (aphids, caterpillars, raspberry beetle) in the Lviv region. The objectives of the study were to determine the effect of entomophages (ladybugs, trichogramma) and bioinsecticides on reducing the count of major raspberry pests and the level of fruit damage, to assess the economic efficiency of individual and combined use of biological protection methods, and to investigate compliance with organic farming standards and the effects on crop quality.

MATERIALS AND METHODS

The study was conducted on raspberry plantations in the Lviv region during the growing season of 2023, from May to August. The region is characterised by a temperate continental climate with an average summer temperature of around +18...+22°C and sufficient rainfall (60-90 mm per month), which creates favourable conditions for raspberry cultivation. The experiment was conducted on the Polana variety of raspberry, which is known for its high yield and popularity among farmers. The study followed the ethical standards set out in the Convention on International Trade in Endangered Species of Wild Fauna and Flora (1973) and the Convention on Biological Diversity (1992). The plots selected for the experiment were characterised by loamy soil with good moisture retention capacity, which created favourable conditions for raspberry growth and research.

Three different biological control agents were employed to control the main pests. Ladybugs (*Coccinellidae*) were used to control aphids (*Aphis ruborum*), which is one of the most harmful insects for raspberry plantations. Ladybugs were released on each bush in an amount sufficient to naturally reduce the pest population. To reduce the number of caterpillars damaging the fruit, the study used *Trichogramma spp.* Trichogramma was placed in capsules in areas with caterpillars, providing a long-term control effect. To control the raspberry beetle (*Byturus tomentosus*), which damages both fruit and leaves, bioinsecticides based on *Bacillus thuringiensis* were used. All these products were certified according to organic farming standards, specifically the European Regulations EC 834/2007 (2007) and EC 889/2008 (2008), which regulate the use of biological products for pest control in organic agriculture. These products were applied to the plants in the form of spraying according to the manufacturer's recommendations.

The experimental design included a control group and four experimental groups, with 50 bushes in each group. The control group did not use any protection products, which helped to estimate the natural level of pest abundance and yield losses. The first experimental group received only ladybugs, the second – only trichogramma, while the third – only bioinsecticides. The last group, the combined group, included all three methods of protection at once, which helped to assess the interaction and synergistic effect. The assessment of the effectiveness of the methods was based on counting the count of pests and the level of fruit damage. Several methods of data collection were used for this purpose. Aphid numbers were determined by visual inspection of leaves and shoots, considering the number of individuals per bush. Caterpillars and raspberry beetle were counted using traps and random inspection of plants. The percentage of damaged fruit in each group was also assessed to determine the influence of pests on yield. All data were collected on a daily basis, which helped to identify the dynamics of changes in the count of pests and fruit damage. This helped to assess both the short-term effectiveness of the methods in the first weeks after application and the long-term effects throughout the entire period of active growth, flowering, and ripening of berries.

The study employed bioinsecticides based on *Bacillus thuringiensis* (Bt), which are effective against lepidopteran pests, to control caterpillars. The preparation consisted of a spore-crystal complex of the bacterium, which, when ingested by the pest's digestive system, caused the destruction of the intestinal wall, leading to death. The preparation was applied in the form of a working solution with a concentration of 1.5-2.0 litres per 100 m^2 of raspberry plantations. The treatment was performed three times during the growing season with an interval of 10-14 days, starting from the first signs of caterpillar damage. The solution was applied using a knapsack sprayer, ensuring uniform coverage of all aerial parts of the plants. To preserve the activity of the product, the treatment was performed in the evening to avoid exposure to ultraviolet radiation. This ensured a comprehensive evaluation of each method and helped to develop recommendations for implementing these approaches in practice.

RESULTS

Dynamics of aphid counts. The study was conducted on raspberry plantations in the Lviv region during the growing season of 2023, from May to August on raspberry plantations in the Lviv region and aimed to evaluate the effectiveness of biological methods of plant protection against pests. The region with a temperate continental climate, an average temperature of +18...+22°C during the growing season and monthly precipitation of 60-90 mm creates suitable conditions for growing berry crops. At the same time, these conditions contribute to the active reproduction of aphids (*Aphis ruborum*), which is one of the most harmful insects that causes great damage to raspberry crops. The relevance of the study was confirmed by the need to develop effective environmentally friendly protection methods for organic farming (Shabliy *et al.*, 2025).

In the control group, where no protection was applied, the aphid population grew rapidly. The initial 50 individuals per bush reached 300 by the end of the 30-day period. This indicated a six-fold increase in counts caused by favourable conditions for the pest's reproduction. Each new generation considerably increased the pressure on the plants, which could lead to a complete loss of yield. This situation is typical for uncontrolled pest spread in agricultural conditions. The experimental group, where ladybugs (*Coccinellidae*) were used to control aphids, demonstrated a completely different dynamic. In the first 10 days after the release of ladybugs, the count of aphids decreased by 40% – from 50 to 30 specimens per bush. Over the next 10 days, the population decreased by 70%, reaching 15 specimens. By the end of the experiment, the count of pests in this group was only 7 per bush, which corresponds to an overall reduction of 85%. This confirms the high efficiency of ladybugs as a natural method of protection.

The results of comparing the control and experimental groups demonstrated the considerable advantages of the biological approach. On the 10th day of the experiment, the count of aphids in the control group increased to 120 individuals, while in the group with ladybugs it decreased to 30. At the end of the experiment, the difference became even more pronounced: 300 specimens in the control group versus 7 in the experimental group. This is 43 times less, which demonstrates the effectiveness of a natural method of protection that can considerably reduce the count of pests (Medvid, 2021). It is especially significant to note the rapid efficacy of the method. In the first 20 days after the release of ladybugs, the largest decrease in aphid numbers was recorded, which is explained by the active predatory behaviour of ladybugs. This period was key to reducing the pest population to a safe level. The further slowdown in the rate of population decline observed in the final 10 days indicated that the minimum population level was reached, which the ladybugs stably maintained until the end of the experiment.

The data in Table 1 also underline the significance of biological control in organic farming. In the control group, an uncontrolled increase in the aphid population was observed, which could have caused considerable crop losses and negatively affected the economic performance of the farm. The use of ladybugs helped to reduce the count of pests to a minimum, without harming the environment or using chemicals. The biological method of protection is not only environmentally friendly, but also economically justified, as the cost of purchasing and releasing ladybugs was considerably lower than the potential damage from the uncontrolled spread of aphids.

***Table 1**. Dynamics of the counts of aphids*

Observation period	Control group (average count of aphids per 1 bush)	Experimental group (average count of aphids per 1 bush)	Reduction in the counts in the experimental group (%)
Start of the experiment	50	50	0
10 days later	120	30	40
20 days later	200	15	70
30 days later	300	7	85

***Source:** created by the authors*

Thus, the table clearly illustrates the effectiveness of ladybugs in aphid control. The data confirmed that the use of this method can be a successful tool for protecting raspberry plantations, especially in organic farming, where the use of chemical pesticides is limited (Todosiychuk, 2024). The considerable reduction in aphid numbers in the experimental group compared to the control group demonstrates the potential of ladybugs as a key element of an integrated plant protection system.

Dynamics of caterpillar counts. Caterpillars are another major pest of raspberry plantations in the Lviv region. Caterpillar activity leads to fruit damage, which reduces the quality and quantity of the crop. The study evaluated the effectiveness of *Trichogramma spp*. in controlling caterpillar numbers and reducing the impact on yield. *Trichogramma* is a microscopic parasite that lays eggs in caterpillar eggs, stopping development and greatly reducing the damage caused by the pests. In the experimental plots, cardboard capsules with a *Trichogramma* were used, which were placed on every fifth raspberry bush. The control group was left without the use of any protective equipment. The level of fruit damage was performed every 10 days during the entire growing season. Both the level of fruit damage and the total number of caterpillars in the control and experimental plots were assessed. Table 2 shows a clear difference in the fruit damage levels between the control and experimental groups throughout the study, which highlights the effectiveness of *Trichogramma* in caterpillar control. In the control group, where no protection products were applied, the level of fruit damage steadily increased with each observation period. At the beginning of the experiment, about 10% of the fruit was damaged, which can be considered a natural level of damage in the presence of caterpillars without intervention. However, after 30 days, this figure increased to 55%. Such a rapid increase in the level of damage indicates active pest reproduction and a considerable impact on yield.

In the control group, the caterpillars developed freely, causing damage to the fruit. The activity was conditioned by favourable environment, including the absence of natural enemies or protective measures. The caterpillars damaged the fruit, resulting in losses for commercial use and considerably reducing the overall quality of the crop. This increase in damage levels demonstrates how quickly the negative impact of caterpillars can progress if no action is taken to control their numbers. In the experimental group, where the *Trichogramma* was used, the situation was radically different. Within 10 days after the application of the *Trichogramma*, the level of damaged fruit decreased by 40% compared to the control group, amounting to 15% versus 25%. This first reduction was caused by the fact that the *Trichogramma* began to act actively, laying its eggs in the eggs of the caterpillars, which stopped development. Due to this, the caterpillars did not reach the stage at which they could harm the fruit, which explained the rapid effect in the first days after application. Twenty days after the start of the experiment, the effectiveness of the *Trichogramma* became even more evident. The level of damaged fruit in the experimental group decreased to 12%, which corresponded to a 70% reduction in damage compared to the control group. During this period, the *Trichogramma* demonstrated its ability to effectively control the count of caterpillars in a long period. This suggests that the effect of *Trichogramma* is not limited to a brief period after application, but has a long-term effect, maintaining a low level of pest numbers (Vasyliev, 2021; Shahini *et al.*, 2023). 30 days after the start of the *Trichogramma* application, which corresponded to the end of the main stage of the experiment, the level of damaged fruit in the experimental group was only 10%. This suggests the effectiveness of the method during the key raspberry growing season, although the total growing season of the crop lasted from May to August. This figure was eight times lower than in the control group, where the level of damage reached 55%. This difference clearly demonstrates the benefits of using *Trichogramma* as an effective biological control agent (Table 2).

***Table 2**. Dynamics of the counts of caterpillars*

Observation period	Control group (count of caterpillars per 1 m^2)	Experimental group (count of caterpillars per 1 m^2)	Reduction in the counts in the experimental group (%)
Start of the experiment	5	5	0
10 days later	12	8	33
20 days later	20	6	70
30 days later	30	5	83

***Source:** created by the authors*

Notably, *Trichogramma* is a cost-effective means of protection. Its use requires minimal costs compared to the losses that can be caused by the uncontrolled spread of caterpillars (Hablak, 2022). In the control group, where the level of fruit damage reached 55%, farmers could have lost a significant portion of their crop. At the same time, in the *Trichogramma* group, the level of damage stayed minimal, ensuring satisfactory fruit quality and maintaining yields.

Effects of bioinsecticides on reducing crop losses caused by raspberry beetle. The raspberry beetle (*Byturus tomentosus*) is one of the main pests of raspberry plantations, which causes major yield losses due to damage to berries. The study evaluated the effectiveness of a combination of bioinsecticides based on (*Bacillus thuringiensis*) in reducing damage from this pest. The bioinsecticides were applied to the experimental plots, while the control group was left untreated. The study considered the level of crop losses and the counts of raspberry beetles on the bushes.

The data clearly demonstrates the difference between the level of crop losses in the control and experimental groups. In the control group, yield losses increased steadily throughout the study, starting at 10% at the beginning of the experiment and reaching 70% at the end. This indicated that without intervention, the raspberry beetle managed to reproduce freely and cause damage to the crop. At the same time, in the experimental plots where bioinsecticides were used, crop losses were much lower. 10 days after the start of the experiment, losses in the control group increased to 30%, while in the experimental group they stayed at 15%, which indicated a 50% reduction in losses compared to the control plots. After 20 days, crop losses in the control group reached 50%, while in the experimental group they were only 25%, i.e., reduced by half. By the end of the study, after 30 days, the yield losses in the control group reached 70%, while in the experimental group they stayed at 28%. This meant that the combination of bioinsecticides reduced crop losses by 60%.

Analysing these data, it can be concluded that bioinsecticides provided a gradual and stable reduction in the effects of raspberry beetle on yield. The bioinsecticides worked through several mechanisms, including inhibition of the pest's vital functions, which led to a decrease in the counts and, consequently, the level of damage to the berries. Furthermore, the study also showed that the effects of bioinsecticides were long-term. During the entire period of the experiment, the level of crop losses in the experimental group stayed significantly lower than in the control group. This indicated that bioinsecticides had not only a quick but also a long-lasting effect, providing stable protection of plantations. Notably, the use of bioinsecticides did not affect the quality of the fruit in the experimental group. The berries stayed clean and free of pesticide residues, which is significant for organic farming. In the control group, a sizeable proportion of the berries were damaged, resulting in their loss for commercial use (Table 3).

***Table 3**. Effects of bioinsecticides on reducing crop losses caused by raspberry beetle*

Observation period	Control group (yield losses, %)	Experimental group (yield losses, %)	Reduction in the counts in the experimental group (%)
Start of the experiment	10	10	0
10 days later	30	20	33
20 days later	50	25	50
30 days later	70	28	60

***Source:** created by the authors*

Thus, the table demonstrates that the use of a combination of bioinsecticides is an effective solution for raspberry beetle control. The 60% reduction in crop losses confirmed the feasibility of using biological protection products in agriculture, especially in organic production (Tkalenko, 2022; Tanchyk *et al.*, 2024). This method not only minimised the impact of pests on the crop, but also preserved the ecological balance, ensuring the stable production of environmentally friendly products.

Comparison of the effectiveness of protection methods. The analysis of the results of the combined method showed significantly higher efficiency compared to the separate application of each method. The aphids, which in the control group reached 300 specimens in 30 days, were almost completely destroyed in the combined group, where the number decreased to 5 specimens, which corresponded to 98.3% reduction. After 10 days, the number of aphids in the combined group decreased to 20 specimens, demonstrating the high efficiency of ladybugs in combination with other methods. On the 20th day, the number decreased even more – to 10 specimens, which confirmed the stable effects of the combined approach.

The combined method also proved to be extremely effective for caterpillars. In the control group, the level of fruit damage increased from 25% to 55%, while in the combined group it stayed at 5% until the end of the experiment. After 10 days, the losses decreased to 10%, which corresponded to a 60% reduction, while after 20 days, this figure dropped to 8%, providing an 80% reduction in losses. By the end of the experiment, the combined method provided a 90.9% reduction in caterpillar losses, which exceeded the effectiveness of the individual *Trichogramma* application. Raspberry beetle also experienced a considerable reduction under the effects of the combined method. In the control group, crop losses reached 70% by the end of the experiment, while in the combined group this figure stayed at 7%, which corresponded to a 90% reduction in losses. After 10 days, the losses in the combined group decreased to 15%, and after 20 days – to 10%, which demonstrated the stable effectiveness of bioinsecticides in combination with other methods (Table 4).

***Table 4**. Comparison of the effectiveness of protection methods*

Method/Pest	Time (days)	Control group (%)	Combined group (%)	Reduction of losses (%)
Ladybugs (aphids)	10	120	20	83.3
	20	200	10	95
	30	300	5	98.3
Trichogramma (caterpillars)	10	25	10	60
	20	40	8	80
	30	55	5	90.9
Bioinsecticides (raspberry beetle)	10	30	15	50
	20	50	10	80
	30	70	7	90

***Source:** created by the authors*

The combined method also proved to be effective in preserving the crop. Total crop losses in the control groups were significantly higher, while in the combined group, losses stayed minimal for all three pests.

Furthermore, the method ensured environmental safety and met organic farming standards, which is a crucial aspect for farmers (Baker *et al.*, 2019).

Economic analysis of the efficiency of protection methods. Figure 1 illustrates the cost-effectiveness of applied protection methods, clearly demonstrating the benefits of a combined approach. The data confirmed that integrating multiple biological control methods is a cost-effective strategy that helps to reduce yield losses and increases profitability of agricultural production (Concept of development of a biological…, 2023).

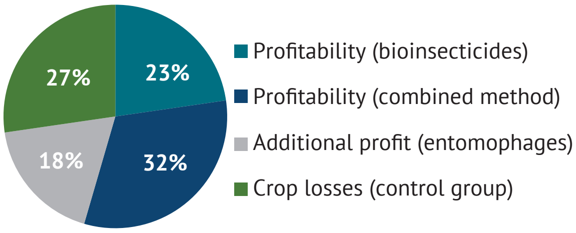

***Figure 1**. Economic analysis of the efficiency of protection methods*
***Source:** created by the authors*

The analysis of the economic efficiency of the applied biological protection methods revealed a substantial difference between the control and experimental groups. In the control group, crop losses amounted to 30%, indicating a severe negative impact of pests on the economic performance of the farm. This level of losses caused extensive financial losses, especially considering the high demand for quality products. The use of entomophages helped to achieve an additional 20% profit. This demonstrated the significant contribution of biological control to cost optimisation and increased agricultural production efficiency (Lee *et al.*, 2024). The method provided a short-term influence but was cost-effective in controlling concrete pest species.

The bioinsecticides used in the study included *Bacillus thuringiensis* (Bt) bacterial preparations, which have proven efficacy against scale pests. The preparation consisted of a spore-crystal complex of the bacterium capable of destroying the intestinal wall of pests, causing death. The dose of the preparation was 1.5-2.0 litres of working solution per 100 m^2 of raspberry plantations, while the treatment was performed three times during the growing season with an interval. The effect of bioinsecticides was less rapid than that of entomophages but stable, which made them suitable for an integrated approach (Basanets, 2024). However, the stability of the product's action ensured a long-term reduction in pest counts and maintained the yield at a stable level. Two weeks after the first treatment, the counts of caterpillars decreased by 50%, and by the end of the experiment – by 70%.

Apart from its effectiveness in reducing pest counts, the use of bioinsecticides positively influenced the farm's economic performance. By reducing crop losses, the profitability of raspberry cultivation increased by 25%. The preparation also showed high compatibility with other protection methods, making it suitable for an integrated approach. The use of bioinsecticides not only reduced the count of pests, but also ensured long-term stable plant protection, which confirmed its efficiency in organic farming. The greatest outcome was demonstrated by the combined method, which provided a 35% increase in profitability. The application combined the benefits of entomophages, bioinsecticides, and *Trichogramma*, creating a synergistic effect. This resulted in a maximum reduction of crop losses and increased economic efficiency.

DISCUSSION

The findings of the study confirmed the high efficiency of biological means of protecting raspberries from major pests, such as aphids (*Aphis ruborum*), caterpillars, and raspberry beetle (*Byturus tomentosus*) in real field conditions. The use of entomophages (ladybugs and *Trichogramma*) and bioinsecticides demonstrated the ability of these methods to reduce pest counts and fruit damage substantially. The best results were obtained with the combined use of these products, which reduced the count of pests by up to 98% and minimise crop losses. Particularly noteworthy was the efficiency of entomophages, which provided a rapid reduction in the count of aphids and other pests in the first weeks after application. Ladybugs showed fast action, while *Trichogramma* demonstrated a stable long-term effect on caterpillars. The bioinsecticides based on *Bacillus thuringiensis* had a slower but sustained effect, especially in the control of raspberry beetles. This combination of various mechanisms of action helped to achieve pronounced efficiency of the combined approach.

M. Kotuła *et al.* (2024) focused on the effects of packaging types on the quality parameters of raspberries during storage. Although the findings of this study emphasised the significance of maintaining berry quality in the post-harvest period, the effects of plant protection methods on the final product were not addressed. The findings of the present study helped to fill this gap, as they proved that the use of biological protection methods, such as entomophages and bioinsecticides, not only mitigates yield losses, but also maintains prominent quality characteristics of the product at the growing stage. The findings of the present study confirmed the effectiveness of biological methods of raspberry protection against pests, which helped to reduce yield losses and increase yield stability. These findings have some similarities with the findings of C. Fuentealba *et al.* (2024), who investigated the quality of raspberries depending on growing conditions. This study indicated that cultivation methods affect the metabolism and quality characteristics of berries. However, C. Fuentealba *et al.* did not analyse plant protection and pest control, which limited the practical relevance of the findings for farmers. The presented findings demonstrated that the integrated use of biological protection methods not only contributes to the preservation of product quality but also ensures a sustainable level of yield in organic farming.

The findings of the present study are also partially consistent with the findings of R. Popa *et al.* (2024), who emphasised the role of raspberry production as a promising area of agribusiness development in a circular economy. The study examined the economic component of raspberry cultivation, focusing on the potential benefits for farmers. The presented findings complement these findings of R. Popa *et al.*, demonstrating that the introduction of biological methods of plant protection can greatly increase the profitability of production by reducing crop losses and minimising the cost of chemicals. Furthermore, the proposed methods are harmoniously integrated into the concept of the circular economy, as they ensure environmental safety and sustainable development of agricultural systems. This integrated approach also contributed to the preservation of fruit quality and economic profitability, which was not analysed in depth in the cited study. R. Anjos *et al.* (2020) compared the effects of organic and conventional raspberry cultivation methods on the phytochemical composition of berries. The researchers noted that organic cultivation methods positively influence the content of biologically active substances in berries, which contributes to the growth in demand for such products among consumers. The present study confirmed this trend, as the use of biological protection methods ensured the preservation of raspberry quality characteristics, such as flavour, texture, and appearance, even with a major reduction in pest counts. However, in contrast to the study by R. Anjos *et al.*, the present findings emphasised the effectiveness of pest control, which is a key factor in ensuring a stable harvest.

The findings obtained are in line with the findings of G. Podedworny *et al.* (2024), who investigated the influence of biodiversity practices on pest and beneficial organism populations in organic raspberry and strawberry cultivation. The researchers emphasised that the use of environmentally friendly practices allows striking a balance between pests and entomophages, which reduces the need for chemical pesticides. The presented findings confirmed this approach, demonstrating that the use of ladybugs, trichogramma, and bioinsecticides can effectively control the count of pests with minimal impact on the ecosystem. However, unlike the study by G. Podedworny *et al.*, the present study paid closer attention to the practical aspects of integrating biological methods into production systems, including assessing profitability and reducing yield losses. The findings are also partially consistent with the findings of M. Ičanović *et al.* (2024), who investigated the effect of humus extract on raspberry quality. The researchers noted that improving soil characteristics contributes to an increase in berry quality. Although the effects of fertilisers were not considered in the present study, the data obtained confirmed that the use of biological protection methods allows maintaining product quality by minimising damage from pests. In contrast to the study by M. Ičanović *et al.*, the present study focused on pest management, emphasising an integrated approach to increasing yields and maintaining ecological balance.

The findings of the present study are partially in line with the findings of M. Drobek *et al.* (2024), who investigated the effects of microbial biostimulants on the antioxidant profile, enzyme activity, and quality of raspberries. The researchers noted that the use of biological agents can greatly improve the quality of fruit by increasing antioxidant activity. Although microbial biostimulants were not used in the present study, the findings confirmed that biological protection methods, such as the use of ladybugs, *Trichogramma*, and bioinsecticides, help to maintain the quality characteristics of berries while minimising damage from pests. This ensures environmental safety of production and high competitiveness of products on the market. The findings also correlate with those presented by M. Kuboń *et al.* (2024), who analysed the use of eco-friendly technologies, specifically the modification of coconut fibres to increase sustainability in dessert raspberry production. Their study focused on the environmental friendliness of production processes that help reduce environmental impact. The findings confirmed the significance of ecological approaches, showing that the use of biological protection methods, such as entomophages and bioinsecticides, can effectively control pests without harming the ecosystem. In contrast to the study by M. Kuboń *et al.*, the present study focused more on the practical aspects of pest control, including an assessment of the economic efficiency of such methods.

The findings of the study partially coincide with the findings of G. Ilhan (2024), who investigated the ecotypes of wild raspberries in northeastern Turkey. The researchers focused on the ecological adaptation of wild varieties and the potential for use in organic production. Although the present study used the Polana variety, the findings confirmed that biological control methods such as entomophages and bioinsecticides can be effectively applied to both cultivated and wild raspberry varieties to ensure sustainable production. The distinctive feature of the present study lies in the detailed analysis of the effectiveness of concrete pest control agents, which makes it more oriented towards practical implementation. G. Velicevici *et al.* (2024) focused on the evaluation of the characteristics of different raspberry varieties grown in Timis county, Romania. The researchers analysed the effects of cultivar on berry yield and quality. Although the analysis made a valuable contribution to the understanding of raspberry varietal characteristics, the issue of plant protection against pests stayed outside the scope of the study. The findings presented in the current study complemented these findings, demonstrating that the use of biological control methods can ensure stable yields and berry quality regardless of varietal characteristics, creating a universal solution for organic farming.

The discussion results confirmed that the use of biological control agents, especially in a combined approach, is a highly effective solution for raspberry pest control. The integration of entomophages and bioinsecticides provided a substantial reduction in pest counts, minimised yield losses, and met environmental standards. This study not only highlighted the advantages of biological methods compared to chemical methods but also demonstrated the practical feasibility for farmers focused on organic farming.

CONCLUSIONS

The conducted study helped to assess the effectiveness of biological methods of raspberry protection in organic farming. The key focus was placed on investigating the impact of entomophages, bioinsecticides, and their combined use on pest counts and yield losses. The findings confirmed the promising potential of biological agents in raspberry pest control, specifically in providing effective control of aphids, caterpillars, and raspberry beetles.

The experimental design, which included control and experimental groups, helped to systematically compare the effects of each method individually and in combination. The use of entomophages proved to be particularly effective in rapidly reducing the counts of pests in the early stages of the growing season. *Trichogramma* showed a prominent level of long-term control of caterpillar counts, preventing extensive fruit damage. Bioinsecticides, albeit acting more slowly, had a stable effect at the level of the total raspberry beetle population. The data obtained showed the value of a combined approach that provided the greatest level of protection for the plantations. The synergy of methods contributed to a substantial reduction in the level of harmful effects of insects, as well as maintaining high quality of the crop. This confirmed the feasibility of integrating various biological products into plant protection systems. Apart from the direct effect on yields, the study confirmed that the applied agents followed organic farming standards. The absence of chemical residues in fruits, environmental safety, and biodiversity conservation are major advantages of using biological methods compared to conventional chemical pesticides. The economic assessment also revealed significant advantages of biological control methods. The combined approach minimised yield losses, which increased the profitability of raspberry cultivation. This aspect is crucial for farmers focused on environmentally friendly production and meeting the growing demand for organic products.

Overall, the study confirmed the effectiveness and feasibility of using biological protection products for raspberry cultivation. The findings obtained can be applied to develop recommendations for integrated plant protection systems aimed at increasing yields, economic profitability, and environmental sustainability. The study was limited to the conditions of Lviv region, a single raspberry variety (Polana) and did not factor in the interaction of biological methods with other agronomic practices. Further research could focus on expanding the range of biological agents and investigating their effectiveness in varying climatic conditions.

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CONFLICT OF INTEREST

None.

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Органічне вирощування малини у Львівській області

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Анотація. Метою дослідження було встановлення науково обґрунтованих підходів до використання біологічних методів захисту малини для підвищення і врожайності та якості в умовах органічного землеробства. У статті досліджено ефективність біологічних засобів захисту малини від основних шкідників, зокрема попелиці (*Aphis ruborum*), гусениць та малинового жука (*Byturus tomentosus*), у польових умовах Львівської області. Для проведення експерименту використовували три типи біологічних засобів: ентомофагів (сонечка, трихограма) та біоінсектициди на основі *Bacillus thuringiensis*. Експериментальний дизайн включав контрольну групу без захисту, групи із застосуванням окремих засобів та комбіновану групу, де використовували всі методи одночасно. Чисельність шкідників і рівень пошкоджень плодів аналізували щодекадно протягом вегетаційного періоду, що тривав із травня до серпня. Отримані результати продемонстрували, що комбіноване використання біологічних засобів було найефективнішим. Застосування сонечок зменшило чисельність попелиці на 85%, трихограма забезпечила зниження рівня пошкодження плодів гусеницями на 90%, а біоінсектициди зменшили втрати врожаю через малинову жуку на 60%. У комбінованій групі чисельність шкідників знижувалася до 98%, а втрати врожаю скоротилися до мінімуму. Економічний аналіз підтвердив доцільність застосування біологічних методів: комбінований підхід дозволив підвищити рентабельність вирощування малини на 35%, забезпечуючи водночас відповідність продукції стандартам органічного землеробства. Висновки дослідження свідчать про високу ефективність біологічних засобів захисту для контролю шкідників, економічну вигідність і екологічну безпечність. Результати мають практичне значення для органічного землеробства та можуть бути використані як рекомендації для фермерських господарств

Ключові слова: землеробство; біопрепарати; шкідники; біологічний захист; ентомофаги
