
ANALYSIS OF THE ECONOMIC JUSTIFICATION OF THE APPLICATION OF SPIROTETRAMAT IN THE CONTROL OF THE WHITE BUTTERFLY APHID (*TRIALEURODES VAPORARIORUM*) IN GREENHOUSE TOMATO PRODUCTION

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ABSTRACT

The aim of this research was to evaluate the economic efficiency of the spirotetramat 100 g/L SC in controlling the white butterfly aphid (*Trialeurodes vaporariorum*) in greenhouse tomato production within the framework of Integrated Pest Management (IPM). All applied insecticide treatments led to a statistically significant reduction of the pest population in comparison to the untreated control, as well as an increase in the number of healthy fruits and commercial yield. A dose of 0.45 l/ha did not provide a satisfactory level of control (<90%), while a dose of 0.75 l/ha showed high efficiency, comparable to the standard preparation Movento 100 SC. The systemic properties of spirotetramat allow to act on all developmental stages of the pest, including individuals in the inner parts of the leaf, with good compatibility with beneficial organisms. Economic analysis, based on gross margin and other indicators, confirms that the application of spirotetramat in greenhouse tomato production is economically justified and contributes to the sustainable control of *T. vaporariorum*.

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Introduction

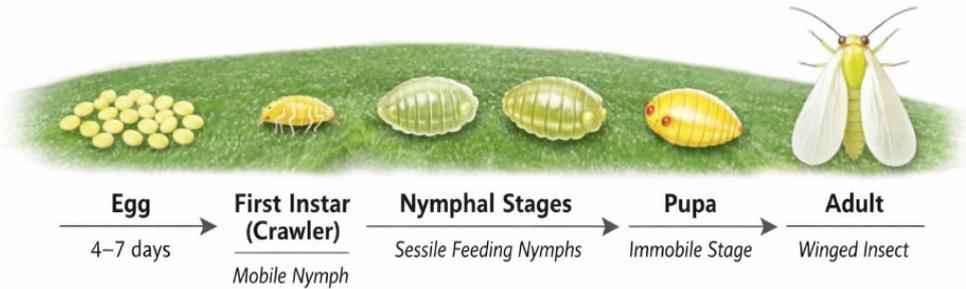
The global development directions, which are adopted by the member country of the United Nations, are based on the strategic framework of sustainable development defined until 2030. Withing this concept, providing sufficient and health-safe food is one of the priority challenges of modern society. Despite this, World Health Organization reports indicate that the problem of hunger and inadequate nutrition still affects a large part of humanity (WHO, 2020). This state of affairs largely stems from difficulties in agricultural production, especially due to the uncontrolled spread of harmful organisms and weed communities, which negatively affect yields. In order to alleviate the mentioned problems, various crop protection strategies are applied in modern agricultural practice (Bajagić et al., 2023; Šević et al., 2025), whereby the use of chemical preparations, especially pesticides of inorganic origin, is usually relied upon.

Tomato (*Lycopersicon esculentum* L.) is an annual herbaceous plant that has an extremely important place in the diet of people worldwide. The fruits are used in different stages of development, from unripe to complete technological maturity, depending on the purpose. The use of tomatoes is based on the use of the fruit in its fresh state, with the growing number of tomato fruits for industrial processing, which implies the intensification of production in protected areas, primarily greenhouses (Cvijanović et al., 2021).

The production of vegetable crops under protected conditions is burdened by numerous biotic stress factors, among which *Trialeurodes vaporariorum* plays a dominant role as the most economically important pest in greenhouse production. This insect achieves a harmful effect primarily by feeding on plant sap, which directly disrupts the physiological processes of plants, which manifests itself by reducing vegetative growth, vitality and marketable quality of fruits. Indirect damage is caused by the secretion of honeydew, which favors the development of sooty fungi from the genus *Asporium*, which reduces the photosynthetic potential of the leaf mass. In addition to the above, *T. vaporariorum* is an efficient vector of various phytopathogenic viruses, further endangering the health status of crops (Liu et al., 2015; Liu and Wang, 2020). The long-term and intensive application of insecticides has led to the appearance of pronounced resistance in the populations of this harmful organism, which significantly complicates its control (Zarev et al., 2025). Although biological agents are increasingly used in modern production for the purpose of population regulation, their effectiveness is often variable and slow-acting, which in conditions of increased number of pests requires additional application of chemical insecticides.

Trialeurodes vaporariorum is a widespread pest that poses a serious threat to greenhouse and greenhouse tomato production. Its developmental cycle includes five clearly defined stages (eggs, larvae, nymph, adult and adult insect) (Figure 1). Depending on the temperature and relative humidity, the duration of the entire cycle ranges from 20 to 30 days, while in optimal microclimatic conditions of the greenhouse it can be shortened to 15–18 days. Such conditions enable the formation of 10–15 generations per year, which leads to a rapid increase in the number of the population and an increased risk of a mass appearance of the pest.

Figure 1. Developmental stages of white butterfly aphid (*Trialeurodes vaporariorum*): eggs, four larval stages and imago - adult



Developmental Stages of the Greenhouse Whitefly (*Trialeurodes vaporariorum*)

Source: <https://www.koppert.com>

Harmful effects of *T. vaporariorum* can be direct or indirect. Direct damage is caused by feeding on plant juice, which reduces the vitality of plants, slows down vegetative growth and reduces the quality of fruits. Indirect damage is due to the secretion of honeydew, which favors the development of sooty fungi (*Apisorium spp.*), reducing the photosynthetic potential of the leaves. In addition, the adults of this harmful insect act as vectors of numerous phytopathogenic viruses, further threatening the health status of crops (Liu et al., 2015; Liu and Wang, 2020). The attack of the pest leads to an aesthetic deterioration of the fruits, while the leaves gradually lose chlorophyll, die and fall off.

The control of *T. vaporariorum* is a challenge due to its pronounced resistance to chemical insecticides. In modern greenhouse systems, biological agents, including predators and parasitoids, that can regulate pest populations are increasingly applied, but their effectiveness is often slower and variable. When populations exceed the economic damage threshold, additional application of selective chemical insecticides is necessary, as part of Integrated Pest Management (IPM). Such an approach makes it possible to maintain the population below a critical level, reduces the negative impact on beneficial organisms and the environment, and contributes to sustainable tomato production in protected areas. Although the assessment of the direct impact of white butterfly aphid on tomato yield is difficult due to the combined effects of other biotic and abiotic factors, available data indicate a significant economic loss in greenhouse production. Fast reproduction and the possibility of forming several generations per year enable populations to exceed the economic threshold of harm in a relatively short period of time. When the abundance of the pest exceeds the threshold, there is a decrease in the photosynthetic potential of the leaf mass, degradation of the fruits and a decrease in the overall yield. Therefore, monitoring population dynamics and timely application

of integrated plant protection measures, including biological and selective chemical methods, is a key strategy to maintain populations below critical levels and minimize economic losses. Such an approach enables sustainable greenhouse production of tomatoes, reducing the negative effects on beneficial organisms and the environment, while at the same time ensuring a stable and high-quality yield.

Combining chemical and biological insecticides has great potential in pest control, but it can lead to different outcomes, from synergistic to antagonistic effects (Elanchezhyan et al., 2025). Improper application of insecticides can cause damage or total loss of yield. In addition to achieving the desired level of efficiency, the application of chemical agents is also limited by the risk of phytotoxic effects on plants.

Spirotetramat is a systemic insecticide from tetramic acid (IRAC group 23) with a unique mechanism of action - inhibition of lipid biosynthesis in targeted harmful organisms, especially in mammals, such as whiteflies, aphids and other similar pests in a wide spectrum of crops (vegetables, fruits, vines, etc.). By acting on lipid metabolism, this compound hinders the development of young stages and reduces the reproductive potential of pests, thereby contributing to their effective control in agricultural crops. Additional importance is reflected in its systematic bilateral translocation through the plant, which effectively enables the action and control of insects hiding on the inside of leaves or young shoots, thus reducing the need for frequent repeated spraying (Dearlove et al., 2024). For example, in oil palm, treatment with spirotetramat (Movento® 150 g/L OD) significantly reduced the population of *Aleurodicus rugioperculatus*, leading to an 81.99–93.30% reduction in the number of larvae and an improved yield by 52.86–70.41%, without noticeable phytotoxic effects and with the preservation of natural enemies *Encarsia* spp. (Badari Prasad et al., 2025). Studies of residues in tomato fruits indicate that spirotetramat and its metabolites degrade relatively quickly and that, when applied in accordance with the recommended doses and withdrawal period, they remain below the maximum allowed residue levels (MRL), which makes it acceptable from the aspect of food safety (EFSA, 2022).

Several studies indicate that spirotetramat can cause sublethal biochemical and physiological changes in non-target organisms and the ability of beneficial entities in agroecosystems. In beneficial parasitoid wasps (*Encarsia formosa*), experimental exposure to spirotetramat caused decreased survival rates, shortened lifespan, and impaired parasitic capacity, suggesting negative effects on biological pest controllers (Yang et al., 2024). These results indicate that residual concentrations of spirotetramat can impair the ability of natural enemies of insect pests to effectively control pest populations. In addition, tests indicate that under long-term exposure, spirotetramat can alter the activity of protective enzymes and cause oxidative stress in earthworms (*Eisenia fetida*), which is an indicator of potential genotoxic and biochemical stress in soil-dwelling organisms (Zhang et al., 2015).

Although the acute toxicity of spirotetramat to mammals is considered to be relatively low and does not indicate a highly acute hazard to humans or large mammals at standard

exposures, its sublethal and ecotoxic effects on non-target organisms indicate the need for careful use and risk assessment, especially in the context of IPM (Integrated Pest Management) programs (Kim et al., 2024).

Vegetable production represents one of the most economically intensive and potentially profitable branches of agricultural production, with a significant impact on the overall development of the agricultural sector (Subić et al., 2007). The high level of production intensity, short production cycles and the possibility of achieving several harvests during the year make vegetable growing an important source of income for agricultural farms, especially in conditions of limited land resources (Cvijanović and Petrović, 2025). At the same time, the economic results of this production depend to a large extent on the general level of economic development, the availability of modern inputs and the level of technological equipment of the producers. Vegetable production requires significant employment of labor and a high level of investment in raw materials, machinery and irrigation systems, which further emphasizes the importance of rational cost management (Rajić et al, 2023). Intensive land use, with the possibility of changing two to three different vegetable crops during the year, allows for an increase in the economic efficiency of production, but at the same time increases the risks of the appearance of harmful organisms and significant economic losses. In such conditions, the choice of effective and economically justified plant protection measures is one of the key factors in preserving yield, product quality and overall profitability of vegetable production.

The area under vegetable crops in the Republic of Serbia in 2024 was 74.2 thousand hectares, which represents a decrease of 10.1% compared to 2023, as well as a drop of approximately 20% compared to the average five-year level. Despite the reduction of total areas, vegetable production in 2024 reached a total volume of 1.47 million tons, which is 12.2% more than the previous year and about 9% above the five-year average (Statistical Office of the Republic of Serbia). Such indicators point to productivity growth and production intensification, but at the same time emphasize the increased exposure of production to economic and production risks. The structure of sown areas under vegetable crops shows that potatoes have a dominant share with 30.3% of the total area (22.5 thousand ha). They are followed by peppers with a share of 12% (8.9 thousand ha) and tomatoes with 9.4% (7 thousand ha). The significant participation of tomatoes in the structure of vegetable production, especially in intensive cultivation systems, additionally confirms its economic importance and the need for the application of effective and economically justified plant protection measures, in order to preserve the yield, product quality and overall profitability of production (Petrović et al, 2024).

Yields in the sector of vegetable production in 2024 increased by 16.2% compared to 2023. Productivity growth is most pronounced in peppers, which achieved an average yield higher by 67% (20.1 t/ha) compared to the previous year, as well as in tomatoes, whose average yield increased by 60.5% (23.5 t/ha), although the areas under these crops were 3–4% smaller than in 2023 (Statistical Office of the Republic of Serbia). These data indicate a significant increase in the intensity of production and a more

efficient use of production factors in the vegetable sector. The reasons for the growth of production in this sector, in addition to the favorable agro-climatic conditions during 2024, can be largely attributed to the application of modern technologies and improved production inputs (Petrović et al., 2024). Their application directly affects the increase in yield and the improvement of product quality, thus achieving higher profitability of production (Cvijanović et al., 2023). In the conditions of reduced sowing areas, yield growth becomes a key factor in preserving the economic viability of production, where the rational choice of technological measures and means for plant protection is of particular importance in intensive cultivation systems, such as the production of tomatoes in a protected area (Cvijanović et al., 2023).

When it comes to the economic efficiency of vegetable production in the Republic of Serbia, the best economic and financial results are recorded by the production of peppers and tomatoes (Petrović et al., 2021), and the biggest influence on the results is yield and price, which vary from year to year. The fluctuation of tomato prices has a pronounced seasonal character (Petrović et al., 2022), and depends on whether the market sells tomatoes produced in Serbia or from imports, as well as whether the tomatoes are produced in an open field or in a protected area where production costs are significantly higher. Also, production costs have a significant effect on the achieved results, which must be controlled so that the consumption of inputs in tomato production will be optimal, as well as the optimal use of labor. Transportation costs can also be a significant cost in production (Savić et al., 2020), which can increase costs and thus the price of the product. One of the measures that can influence the reduction of the risk of production, i.e. the realized profit, is certainly production insurance, which to a large extent can influence the loss due to the occurrence of certain harmful events, to some extent to be covered (Petrović et al., 2020).

The aim of this research is the economic evaluation of the sustainable production of tomatoes in a closed system, based on the principles of integral plant protection, with special reference to the biological effectiveness of the insecticide Spirotetramat 100 g/L SC in the control of white butterfly aphids (*Trialeurodes vaporariorum*).

Materials and methods

Analyzes of the effectiveness of insecticides based on spirotetramat in the production of tomatoes in protected areas were carried out on four experimental fields (locations) according to a completely random block system in 4 repetitions, where the tested treatments are given in Table 1, and the basic parameters of the application of the treatment in Table 2. The active substance spirotetramat was applied in an amount of 0.45-0.75 l/ha. The amount of water used for treatments was 300 l/ha. The ready-made working solution for treating tomatoes contained 0.225–0.370% of the active substance spirotetramat.

Table 1. Treatments tested in trials

Treatment	Application amount in 300 l/ha H ₂ O
Control (untreated area)	-
Spirotetramat 100G/L SC	0.45 l/ha
Spirotetramat 100G/L SC	0.75 l/ha
Movento 100 SC	0.75 l/ha

Source: Authors' own research

Table 2. Basic parameters of treatment application

Location	Mužlja	Omoljica	Valjevska kamenica	Bela Crkva
Number of treatments	1	1	1	1
Date	13.06.2022.	14.06.2022.	29.07.2023.	24.07.2023.
Phenophase of plants	BBCH 75-76	BBCH 75-77	BBCH 67-81	BBCH 68-81
Method of application	Foliar application			
Applicatin device	Back sprayer Euro Pulve (France)			
Variety/hybrid	Runner	Pink rock	Novosadski jabučar	Big Beef
First assessment – before treatment	13.06.2022	14.06.2022.	29.07.2023.	24.07.2023.
Second assessment	21.06.2022.	22.06.2022.	05.08.2023.	01.08.2023.

Source: Authors' own research

Biological efficacy testing was conducted according to standardized EPPO methods: PP 1/36 (3) – Evaluation of insecticide efficacy; PP 1/152 (4) – Evaluation of the efficacy of plant protection products: study design and analysis; PP 1/181 (5) – Evaluation of plant protection product efficacy: performance and reporting; PP 1/135 (4) – Phytotoxicity assessment; PP 1/225 (2) – Determination of the minimum effective dose; PP 1/239 (3) – Expression of the dose of plant protection products. According to the EPPO method PP 1/36, live larvae and adults were counted on the leaves. The number of larvae was determined on one, previously marked and fully opened leaf per plant in the experimental plot (10 leaves in total), while the number of adults (imagos) was recorded on the tops of the plants, including the first fully opened leaves, taking care not to disturb the insects in order to make the count as accurate as possible. Finally, healthy fruits were counted, which directly affect the quality and quantity of the yield. Fruits were counted on 10 test plants, by counting 10 fruits from the bottom up. Assessments were performed immediately before treatment and 8 days after treatment.

The statistical processing of the results was carried out in accordance with the recommendations of the EPPO method PP 1/152 (4). The significance of differences between means was tested by analysis of variance (ANOVA). If the analysis showed a statistically significant difference ($p < 0.05$), further comparisons of pairs of mean

values were carried out using the LSD test (Fisher's method) at the significance level $\alpha = 0.05$, in order to determine between which, mean values there is a significant difference (post hoc test). Mean values marked with the same letter do not differ statistically significantly, while values marked with different letters show a significant difference. Statistical analysis (ANOVA and LSD post hoc test) was performed in the Minitab 18 software package.

The efficiency of the insecticide was determined using the Henderson-Tilton formula:

$$\text{Efficacy \%} = 1 - \frac{n \text{ in control before treatment} \times n \text{ in treatment after treatment}}{n \text{ in control after treatment} \times n \text{ in treatment before treatment}} \times 100$$

For the purposes of analyzing the economic efficiency of tomato production with the use of spirotetramat as part of the integral protection of plants from the white butterfly aphid (*Trialeurodes vaporariorum*), a calculation methodology based on variable costs, i.e. gross margin analysis, was applied. This approach makes it possible to see the direct economic effects of insecticide application through the ratio of realized income and variable production costs (Gogić, 2014).

The data used in the economic analysis were obtained on the basis of the results of multi-location trials conducted in four localities. The calculation of the gross margin included variable costs relevant to the production of tomatoes in the protected area, including the costs of plant protection, as well as the yield and quality of the fruits.

Based on the results of the gross margin calculation, additional economic indicators of tomato production were calculated, including the profitability of production, the lower breakeven point and the cost price of tomato production. These indicators enable a comprehensive assessment of the economic justification of the use of spirotetramat in the integral protection of tomatoes, as well as an overview of its impact on the overall economic sustainability of production.

Results

The results of testing the biological efficiency of the preparation Spirotetramat 100 G/L SC in controlling larvae and adults of *Trialeurodes vaporariorum* species on tomatoes grown in a protected area are shown in tables 3–10. Tables 3-4, 5-6, 7-8 and 9-10 show the results obtained in the localities of Mužlja, Omoljica, Valjevska Kamenica and Bela Crkva. Specifically, Tables 3, 5, 7 and 9 show the number of live larvae and adults before treatment, while Tables 4, 6, 8 and 10 show the abundance and efficacy of insecticides eight days after treatment.

All insecticide treatments, in all post-treatment evaluations and in all localities, showed statistically highly significant differences compared to the untreated control. Spirotetramat 100 G/L SC at a concentration of 0.45 l/ha at all four locations showed an efficiency lower than 90%, which is why this dose cannot be recommended for successful control of *T. vaporariorum*. In

the amount of 0.75 l/ha, the examined preparation Spirotetramat 100 G/L SC showed high efficiency in suppressing *T. vaporariorum*, which was at the level of the standard Movento 100 SC, applied in the amount of 0.75 l/ha. At the minimum effective amount of 0.45 kg/ha, the examined preparation Spirotetramat 100 G/L SC showed a significantly lower efficiency compared to the standard Movento 100 SC.

The number of greenhouse whitefly individuals on tomato plants differed depending on the locality and experimental plot (Tables 3–10). The species *T. vaporariorum* was mostly homogeneously present within the experimental plots. The average number of larvae on 10 leaves, in the untreated control immediately before treatment, ranged from 286 at the Mužlja location to 554 at the Valjevska kamenica location, while the average number of imagos ranged from 69.5 at the Mužlja location to 110 at the Bela Crkva location. The number of larvae and adults of *T. vaporariorum* after treatment was significantly reduced in all treated plots.

Table 3. The number of live larvae and imagoes of the species *T. vaporariorum* determined immediately before the treatment - preliminary assessment at the Mužlja locality

No.	Treatment		The number of live larvae and imagoes of <i>T. vaporariorum</i>				Σ	Ms	Sd
			A	B	C	D			
1	Untreated control	larvae	324	286	441	502	1553.0	388.25ab	100.5
		imagoes	84	42	73	79	278.0	69.50a	18.9
2	Spirotetramat 100 G/L SC (0.45 l/ha)	larvae	595	410	417	548	1970.0	492.50a	93.3
		imagoes	114	73	62	113	362.0	90.50a	26.9
3	Spirotetramat 100 G/L SC (0.75 l/ha)	larvae	486	298	478	513	1775.0	433.75ab	98.3
		imagoes	74	84	106	94	358.0	89.50a	13.7
4	Movento 100 SC (0.75 l/ha)	larvae	310	345	413	329	1397.0	349.25b	44.8
		imagoes	70	123	83	84	360.0	90.00a	22.9

Source: Authors' own research. Ms- mean value, Σ - sum, Sd- standard deviation $p=0.452$; mean values marked with the same letter do not differ statistically significantly.

Table 4. The number of live larvae and adults of the species *T. vaporariorum* and the effectiveness of insecticides in the Mužlja locality 8 days after treatment

No.	Treatment		The number of live larvae and imagoes of <i>T. vaporariorum</i>				Σ	Ms	Sd	Efficiency (%)	Efficiency compared to standard (%)
			A	B	C	D					
1	Untreated larvae	control	414	399	595	637	2045.0	511.25a	122.3	-	-
		imagoes	125	111	142	174	552.0	138.00a	27.1	-	-
2	Spirotetramat 100 G/L SC (0.45 l/ha)	larvae	137	94	81	152	464.0	116.00b	33.9	82.11	85.02
		imagoes	28	22	39	34	123.0	30.75b	7.4	82.89	84.55
3	Spirotetramat 100 G/L SC (0.75 l/ha)	larvae	35	17	35	48	135.0	33.75bc	12.7	94.22	97.56
		imagoes	3	0	10	5	18.0	4.50c	4.2	97.47	99.42

No.	Treatment		The number of live larvae and imagos of <i>T. vaporariorum</i>				Σ	Ms	Sd	Efficiency (%)	Efficiency compared to standard (%)
			A	B	C	D					
4	Movento 100 SC (0.75 l/ha)	larvae	4	17	22	20	63.0	15.75c	8.1	96.58	100.0
		imagos	0	6	7	1	14.0	3.50c	3.5	98.04	100.0

Source: Authors' own research. Ms- mean value, Σ - sum, Sd- standard deviation $p_1=0.000$ for larvae $p_2=0.000$, mean values marked with the same letter do not differ statistically significantly.

Table 5. The number of live larvae and adults of the species *T. vaporariorum* determined immediately before the treatment - preliminary assessment at the Omoljica site

No.	Treatment		The number of live larvae and imagos of <i>T. vaporariorum</i>				Σ	Ms	Sd
			A	B	C	D			
1	Untreated control	larvae	101	87	54	62	304.0	76.00a	21.8
		imagos	19	31	10	19	79.0	19.75a	8.6
2	Spirotetramat 100 G/L SC (0.45 l/ha)	larvae	47	56	88	114	305.0	76.25a	30.7
		imagos	17	7	18	20	62.0	15.50a	5.8
3	Spirotetramat 100 G/L SC (0.75 l/ha)	larvae	127	73	66	104	370.0	92.50a	28.3
		imagos	42	29	8	17	96.0	24.00a	14.8
4	Movento 100 SC (0.75 l/ha)	larvae	109	81	99	67	356.0	89.00a	18.7
		imagos	39	28	11	31	109.0	27.25a	11.8

Source: Authors' own research. Ms- mean value, Σ - sum, Sd- standard deviation $p_1=0.717$ for larvae $p_2=0.470$ for imagos; mean values marked with the same letter do not differ statistically significantly

Table 6. The number of live larvae and adults of the species *T. vaporariorum* and the effectiveness of insecticides at the Omoljica location 8 days after treatment

No.	Treatment		The number of live larvae and imagos of <i>T. vaporariorum</i>				Σ	Ms	Sd	Efficiency (%)	Efficiency compared to standard (%)
			A	B	C	D					
1	Untreated larvae	control	179	201	144	174	698.0	174.50a	23.5	-	-
		imagos	44	51	26	30	151.0	37.75a	11.7	-	-
2	Spirotetramat 100 G/LSC (0.45 l/ha)	larvae	43	35	47	39	164.0	41.00b	5.2	76.58	76.58
		imagos	7	3	5	6	21.0	5.25	1.7	82.28	82.28
3	Spirotetramat 100 G/L SC (0.75 l/ha)	larvae	0	0	0	0	0.0	0.00b	0.0	100.0	100.0
		imagos	1	0	1	0	2.0	0.50b	0.6	98.91	99.39
4	Movento 100 SC (0.75 l/ha)	larvae	0	0	0	0	0.0	0.00b	0.0	100.0	100.0
		imagos	0	1	0	0	1.0	0.25b	0.5	99.52	100.0

Source: Authors' own research. Ms- mean value, Σ - sum, Sd- standard deviation $p_1=0.000$ for larvae $p_2=0.000$ for imagos; mean values marked with the same letter do not differ statistically significantly

Table 7. The number of live larvae and imagos of the species *T. vaporariorum* determined immediately before treatment - preliminary assessment at the Valjevka kamenica site

No.	Treatment		The number of live larvae and imagos of <i>T. vaporariorum</i>				Σ	Ms	Sd
			A	B	C	D			
1	Untreated control	larvae	342	211	396	298	1247.0	311.75a	78.2
		imagos	117	144	98	81	440.0	110.00a	27.0
2	Spirotetramat 100 G/L SC (0.45 l/ha)	larvae	255	196	232	304	987.0	246.75a	45.2
		imagos	94	108	74	114	390.0	97.50a	17.8
3	Spirotetramat 100 G/LSC (0.75 l/ha)	larvae	239	347	187	202	975.0	243.75a	72.2
		imagos	68	87	121	110	386.0	96.50a	23.7
4	Movento 100 SC (0.75 l/ha)	larvae	179	208	300	154	841.0	210.25a	63.8
		imagos	88	70	111	76	345.0	86.25a	18.1

Source: Authors' own research. Ms- mean value, Σ - sum, Sd- standard deviation $p_1=0.230$ for larvae $p_2=0.527$ for imagos; mean values marked with the same letter do not differ statistically significantly

Table 8. The number of live larvae and adults of the species *T. vaporariorum* and the effectiveness of insecticides at the Valjevka kamenica location 8 days after treatment

No.	Treatment		The number of live larvae and imagos of <i>T. vaporariorum</i>				Σ	Ms	Sd	Efficiency (%)	Efficiency compared to standard (%)
			A	B	C	D					
1	Untreated larvae	control	471	362	554	425	1812.0	453.00a	80.8	-	-
		imagos	222	269	213	181	885.0	221.25a	36.4	-	-
2	Spirotetramat 100 G/L SC (0.45 l/ha)	larvae	69	42	72	81	264.0	66.00b	16.8	81.59	82.67
		imagos	26	37	24	31	118.0	29.50b	5.8	84.96	82.67
3	Spirotetramat 100 G/L SC (0.75 l/ha)	larvae	7	13	10	8	38.0	9.50b	2.6	97.32	98.61
		imagos	4	7	5	0	16.0	4.00b	2.9	97.94	98.61
4	Movento 100 SC (0.75 l/ha)	larvae	4	0	7	5	16.0	4.00b	2.9	96.69	100.0
		imagos	2	4	0	0	6.0	1.50b	1.9	99.14	100.0

Source: Authors' own research. Ms- mean value, Σ - sum, Sd- standard deviation $p_1=0.000$ for larvae $p_2=0.000$ for imagos; mean values marked with the same letter do not differ statistically significantly

Table 9. The number of live larvae and imagoes of the species *T. vaporariorum* determined immediately before the treatment - preliminary assessment at the Bela Crkva site

No.	Treatment		The number of live larvae and imagoes of <i>T. vaporariorum</i>				Σ	Ms	Sd
			A	B	C	D			
1	Untreated control	larvae	277	199	315	303	1094.0	273.50ab	52.1
		imagoes	186	119	231	210	746.0	186.50a	48.6
2	Spirotetramat 100 G/L SC (0,45 l/ha)	larvae	302	189	247	265	1003.0	250.75b	47.1
		imagoes	114	98	150	86	448.0	112.00b	27.8
3	Spirotetramat 100 G/L SC (0,75 l/ha)	larvae	384	407	322	290	1403.0	350.75a	54.1
		imagoes	220	133	80	185	618.0	154.50ab	61.2
4	Movento 100 SC (0,75 l/ha)	larvae	266	323	410	333	1332.0	333.00a	59.2
		imagoes	95	150	203	142	590.0	147.50ab	44.2

Source: Authors' own research. Ms- mean value, Σ - sum, Sd- standard deviation $p_1=0.063$ for larvae $p_2=0.222$ for imagoes; mean values marked with the same letter do not differ statistically significantly

Table 10. The number of live larvae and adults of *T. vaporariorum* species and the effectiveness of insecticides at the Bela Crkva location 8 days after treatment

No.	Treatment		The number of live larvae and imagoes of <i>T. vaporariorum</i>				Σ	Ms	Sd	Efficiency (%)	Efficiency compared to standard (%)
			A	B	C	D					
1	Untreated larvae	control	413	301	420	411	1545.0	386.25a	57.0	-	-
		imagoes	279	233	350	317	1179.0	294.75a	50.4	-	-
2	Spirotetramat 100 G/L SC (0.45 l/ha)	larvae	96	74	82	77	329.0	82.25b	9.7	76.77	78.06
		imagoes	38	39	52	44	173.0	43.25b	6.4	75.57	76.39
3	Spirotetramat 100 G/L SC (0.75 l/ha)	larvae	15	18	20	14	67.0	16.75c	2.8	96.62	98.24
		imagoes	7	3	10	5	25.0	6.25bc	3.0	97.44	98.49
4	Movento 100 SC (0.75 l/ha)	larvae	8	9	8	6	31.0	7.75c	1.3	98.35	100.0
		imagoes	3	0	5	2	10.0	2.50c	2.1	98.93	100.0

Source: Authors' own research. Ms- mean value, Σ - sum, Sd- standard deviation $p_1=0.000$ for larvae $p_2=0.000$ for imagoes; mean values marked with the same letter do not differ statistically significantly

If the preparation Spirotetramat 100 G/L SC is applied in accordance with the instructions for use, it does not show phytotoxic effects on the tomato crop in the protected area. The assessment of the quality of the fruits is expressed in Table 11, as well as the yield per unit of measure (kg/500 m²) (Table 12), where it can be concluded that the insecticide Spirotetramat 100 G/L SC, in a concentration of 0.75 l/ha, is reliable in the protection of tomatoes, given that during the counting, no negative impact through the phytotoxicity of tomatoes was noted, and the yield of tomatoes achieved by applying the investigated preparation was comparable to the standard live preparation.

Table 11. The number of mature healthy tomato fruits

Location	Mužlja	Omoljica	Valjevska kamenica	Bela Crkva
Untreated larvae	0/10	0/10	0/10	0/10
Spirotetramat 100 G/L SC (0.45 l/ha)	4/10	2/10	5/10	5/10
Spirotetramat 100 G/L SC (0.75 l/ha)	10/10	10/10	9/10	10/10
Movento 100 SC (0.75 l/ha)	9/10	9/10	9/10	9/10

Source: Authors' own research

Table 12. Tomato yield (kg/500 m²) at different locations

Location	Mužlja	Omoljica	Valjevska kamenica	Bela Crkva
Untreated larvae	1,200	1,250	1,100	1,150
Spirotetramat 100 G/L SC (0.45 l/ha)	1,800	1,850	1,700	1,750
Spirotetramat 100 G/L SC (0.75 l/ha)	7,100	7,150	7,000	7,050
Movento 100 SC (0.75 l/ha)	7,050	7,100	7,000	7,020

Source: Authors' own research

Discussions

The systemic insecticide spirotetramat has emerged as an effective tool in the integrated management of borer and sucker pests, including whiteflies, on protected vegetable crops such as tomatoes. Field and greenhouse applications of spirotetramat show significant reductions in whitefly populations when applied during larval emergence. These results are in agreement with the research conducted by Zarev et al. (2025), it is very important to continuously monitor and control the whitefly and thereby reduce losses in tomato yield in protected areas. In commercial protected tomato production systems, growers have reported significant reductions in whitefly numbers following spirotetramat treatment, with population reductions observed within one to two weeks of application. In one of the studies on strawberry (*Fragaria ananassa*), treatments with spirotetramat significantly reduced the number of eggs and immature forms of the white butterfly aphid under field conditions, where reductions in the number of insect stages were up to 92% at certain stages after treatment, which confirms the broad potential of this active agent in controlling plant sapsuckers (Bi & Toscano, 2007). Comparative studies involving mixtures of spirotetramates, such as spirotetramate in combination with imidacloprid, also illustrate promising efficacy against whitefly on tomato in the greenhouse, suggesting that combining modes of action may improve control under

certain pest pressures (Dearlove et al., 2024). The integration of spirotetramat into Integrated Pest Management (IPM) programs is further supported by its relatively selective action that allows compatibility with beneficial arthropods in some systems, helping to delay the development of resistance in whitefly populations (Agrovodic, 2025). While whiteflies have shown the ability to develop resistance to older chemicals, such as neonicotinoids, the adoption of new systemic insecticides with different modes of action – such as spirotetramat – represents an important resistance management strategy (First report of Bemisia tabaci resistance, 2024).

Table 13. Calculation of the gross margin of tomato production in a protected area (calculation for a 500m² greenhouse)

Location	Omoljica	Mužlja	Bela Crkva	Valjevska Kamenica
Production value (RSD)	929,500	923,000	916,500	910,000
Variable costs (RSD)	278,350	299,350	257,350	243,350
Gross margin (RSD)	651,150	623,650	659,150	666,650

Source: Author's calculation based on data from the experiment

Table 13 shows the data of the gross margin calculations in the localities where trials were conducted to control white butterfly aphid (*Trialeurodes vaporariorum*) using spirotetramat. Data on the production value were presented, calculated based on the obtained yields in the greenhouses where the experiment was conducted, as well as the purchase price, which at the time of the experiment amounted to 130 RSD/kg. The tomato yields in the treatments where spirotetramat was applied ranged between 7 and 7.15 tons. Based on the monitoring of all variable costs during the duration of the experiment, the total variable costs were calculated. The gross margin of tomato production in the protected area at the locations where the trials were conducted, represents the difference between the production value and the variable costs. The data presented in the table show that positive financial results were achieved at all 4 locations, i.e. in all 4 greenhouses, and that the gross margin ranges from 623,650 dinars for the trial conducted in Mužlja to 666,650 dinars for the trial conducted in Valjevska Kamenica. Different amounts of gross margin are due primarily to insignificant differences in production costs, which are primarily related to labor costs, because workers' daily wages differed from place to place.

Table 14. Economic indicators of tomato production in a protected area based on calculated variable costs

Location	Omoljica	Mužlja	Bela Crkva	Valjevska Kamenica
Cost of production (RSD/kg)	38.93	42.16	36.50	34.76
Production profitability (%)	233.93%	208.33%	256.13%	273.95%
Break-even point (kg)	2,141	2,303	1,980	1,872

Source: Author's calculation based on the data obtained in the experiment

The economic indicators of tomato production in a protected area for the control trial of white butterfly aphids (*Trialeurodes vaporariorum*) using spirotetramat, shown in Table 14, confirm the extremely favorable economic results obtained by applying the calculation based on variable costs. Based on the analyzed data, it can be concluded that the production cost of one kilogram of tomatoes in all observed localities is significantly lower than the purchase price, which indicates a high level of economic efficiency of production. The cost price ranged from 34.76 RSD/kg at the Valjevska Kamenica location to 42.16 RSD/kg in Mužlja, while other locations achieved values of 36.50 RSD/kg in Bela Crkva and 38.93 RSD/kg in Omoljica.

Extremely high levels of production profitability, which ranged from 208.33% in Mužlja to 273.95% in Valjevska Kamenica, indicate that the realized gross margin exceeds variable production costs many times over. This means that for every 100 RSD invested in production, between 208 and 274 RSD of profit is realized, which confirms the exceptional economic justification of the applied growing technology in a protected area. In the context of agricultural production, where profitability above 50% is considered very successful, such high indicators indicate a stable and highly competitive production system.

The indicator of the lower coverage point represents the minimum volume of production necessary to cover variable costs at a given purchase price of 130 RSD/kg. In the tests conducted, the lower coverage point ranged from 1,872 kg at the Valjevska Kamenica site to 2,303 kg in Mužlja, while the values for Bela Crkva and Omoljica were 1,980 kg and 2,141 kg, respectively. Compared to the achieved yields, which ranged between 7 and 7.15 tons per 500 m² greenhouse, the minimum yield required to cover variable costs was approximately three to four times lower, indicating low production risk and a high level of investment security in the analyzed greenhouse tomato production system.

Conclusions

The application of spirotetramat 100g/L SC at a dose of 0.75l/ha showed high efficiency in suppressing the white butterfly aphid (*Trialeurodes vaporariorum*) in the greenhouse production of tomatoes. Lower dosages (0.45l/ha) did not provide satisfactory control, which emphasizes the importance of optimal dosage. The systemic properties of spirotetramat enable action on all stages of the pest and compatibility with IPM strategies, while combinations with other insecticides or biological agents can further improve control. The results confirm that spirotetramat is an effective and valuable tool in protecting tomatoes from economic losses caused by *T. vaporariorum*. Based on the obtained results, it can be concluded that the production of tomatoes in the protected area, under the observed production conditions and the purchase price of RSD 130/kg, achieves extremely favorable economic results in all the analyzed localities. Realized gross margins, which range from approximately 650,000 RSD per greenhouse of 500 m², together with extremely high levels of production profitability, confirm the economic justification and stability of this cultivation system. The low cost price per kilogram of product in relation to the market price, as well as the relatively low level of the lower cover point, many times lower than the projected yield, indicate a high degree of investment security and a

significant scope for making a profit even in conditions of reduced yield or unfavorable market trends. The obtained results confirm that the production of tomatoes in a protected area, with the use of spirotetramat in the control of white butterfly laphid (*Trialeurodes vaporariorum*), is economically highly justified and competitive in modern conditions of intensive agricultural production.

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Conflict of interests

The authors declare no conflict of interest.

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