Paradigm

The Influence of Microbial Biostimulators on the Yield and Economic Profitability of Sustainable Production of Pepper (Capsicum Annuum L.)

Marija BAJAGIĆ *
University of Bijeljina, Bosnia and Herzegovina
*Corresponding author, bajagicmarija@yahoo.com

Biljana ŠEVIĆ
Institute for Vegetable Crops Smederevska Palanka, Smederevska Palanka, Serbia
bsevic@institut-palanka.rs

Robert RADIŠIĆ
Institute for Science Application in Agriculture, Belgrade, Serbia
robert.radisic@gmail.com

Goga MARIA
Bucharest University of Economic Studies, Bucharest, Romania
batumirela@gmail.com

Abstract. *Pepper (Capsicum annuum L.) is one of the most important vegetable crops worldwide, with continuously increasing production due to its broad use in fresh consumption and processing. In the Republic of Serbia, pepper production has a significant role, particularly within intensive and sustainable cultivation systems, where producers face rising production costs and growing demands for environmentally friendly technologies. In this context, microbial biostimulants represent a promising approach for improving both yields and economic efficiency. The aim of this study was to evaluate the effects of two microbiological preparations—effective microorganisms (EM) and fungi of the genus Trichoderma—in interaction with agroecological conditions (year), on pepper fruit yield in an organic production system under protected cultivation. A two-factor experiment revealed statistically significant effects ($p < 0.01$) of the applied treatments. The application of Trichoderma sp. resulted in the highest average yield, exceeding the control by 19.35% and the EM treatment by 13.15%. From an economic perspective, the use of microbial biostimulants demonstrated considerable potential for improving production performance. Increased yields, combined with relatively low additional input costs, led to higher gross margins and improved overall profitability per unit area. Furthermore, lower variable costs per kilogram of produced pepper contributed to reduced production costs compared to conventional technological solutions. The results indicate that microbial biostimulants enhance the economic stability of pepper production, reduce production risk, and increase the competitiveness of sustainable and organic cultivation systems.*

Keywords: *economic profitability, sustainable production, effective microorganisms, Trichoderma, Capsicum annuum L.*

Introduction

Pepper (*Capsicum annuum* L.), which belongs to the Solanaceae family, is one of the oldest and most important vegetable crops worldwide. Its importance goes beyond primary agricultural production, because the pepper fruit is considered a functional food due to its extremely rich chemical composition. Biologically active compounds present in the fruit, such as various forms

DOI: 10.2478/picbe-2026-0185
© 2026 M. Bajagić; B. Šević; R. Radišić; G. Maria, published by De Gruyter.
This work is licensed under the Creative Commons Attribution 4.0 License.

of vitamins (especially C, A, E and B complex), flavonoids and carotenoids, play a key role in human nutrition and in support of the immune system, which is particularly relevant in periods of increased risk of respiratory infections, including Covid-19. In addition to them, peppers are an important source of volatile oils, essential fatty acids, proteins, plant fibers and minerals such as potassium, magnesium and iron (Bajagić et al., 2025). As such, it directly contributes to the preservation of human health and the prevention of chronic non-communicable diseases, which places it at the very top of the priorities of modern vegetable science (Rajić et al., 2023).

Pepper production in the Republic of Serbia is one of the most profitable in the vegetable sector (Petrović et al., 2021). Under modern agro-economic conditions, pepper production is increasingly assessed through the lens of sustainable development, technological innovation and system resilience, particularly in the post-pandemic period marked by vulnerable supply chains and rising input and transport costs.

The economic importance of peppers is significant and multifaceted. Peppers are cultivated worldwide and in Serbia on large areas, with diverse applications. In addition to fresh consumption, which dominates in summer and autumn, peppers represent an important raw material for the food industry, undergoing various processing methods such as canning, pickling, freezing, drying and grinding for paprika production, an essential component of global gastronomy. Their high biological value combined with economic accumulativeness makes pepper a strategic crop. Although production is labor-intensive and requires substantial investments, it enables high income per unit area, positioning pepper among the most profitable crops in vegetable production.

Intensive pepper production often relies on excessive agrochemical inputs, increasing both production costs and environmental risks. From an economic perspective, irrational fertilization reduces overall profitability and may negatively affect crop vitality, making plants more susceptible to pests and diseases while compromising fruit quality and food safety. Consequently, modern agricultural science increasingly emphasizes the development of sustainable cultivation models based on integrated and organic principles, aiming to achieve economic profitability alongside ecological regeneration. The share of consumers who are aware of the correlation between nutrition and health is continuously growing globally. The increased demand for food of verified quality, without residues of pesticides and heavy metals, has encouraged experts to return to the research of biological methods that enable the reduction of synthetic inputs. Modern agriculture is at a turning point; while the technological innovations of the 20th century focused exclusively on quantity, the 21st century demands achieving high yields while strictly preserving environmental sustainability. This turnaround implies the selection of tolerant varieties and hybrids, but also the introduction of innovative biotechnological solutions.

Although microbial biostimulants are increasingly promoted in sustainable horticulture, their combined agronomic and economic effects in organic pepper production under protected cultivation remain insufficiently quantified. In recent years, research has increasingly focused on microbial-based biocontrol agents and biostimulants that enhance plant resilience and reduce dependence on synthetic inputs (Bajagić et al., 2023; Šević et al., 2025). Among the most widely applied are effective microorganisms (EM) and beneficial fungi of the genus Trichoderma, which function not only as biological amendments but also as complex biostimulants influencing plant physiology and soil microbial processes.This study aimed to evaluate the effects of microbial biostimulants based on effective microorganisms (EM) and Trichoderma sp. on pepper yield and economic performance in an greenhouse production system. The research was conducted under protected cultivation conditions, reflecting specific microclimatic environments typical for intensive vegetable production. By integrating agronomic and gross margin analysis, the study

provides evidence on the potential of microbial preparations to enhance both productivity and profitability within sustainable cultivation models.

Methodology

A two-factorial experiment was conducted in a protected area for two years at a site in Bačka Topola (Serbia). The Blondi F_1 pepper hybrid was tested in order to determine the influence of individual factors and their interactions on productivity. The experiment was set up as a complete random block system in 3 repetitions, where the area of the greenhouse was 98 m^2, and the size of the elementary plot was 5.5 m^2. The preparation of the greenhouse was carried out in accordance with standard procedures. The seeds were sown in boxes in Klasman TS1 substrate, which is intended for organic production. After that, the seedlings were pinched when the plants were in the phase of the first real leaves in the pots. Soil preparation included basic tillage, application of manure (sheep and beef 3 kg/m²) and additional tillage with a rotary tiller. The plants were planted by hand in double rows with a distance of 40 x 25 cm. In order to ensure the precision of the survey, an isolation belt of 1 m was applied between the blocks, with a distance of 90 cm between elementary plots.

The hybrid pepper Blondi F_1 is characterized by very large fruits, in the babura type, which are light yellow in technological maturity, while in physiological maturity they have an intense yellow color. It belongs to the group of precocious hybrids with high fertility potential, whose fruits are uniform and reach a weight of 200 - 250 g, length about 10 cm and width about 8 cm. The shape of the fruit is cylindrical with 3-4 dividing chambers. The plant is strong, of indeterminate growth, with a highly developed root system, which enables stability due to the load of a large number of formed fruits. The fruits are characterized by a thick pericarp, due to which the fruits retain freshness and turgor for an extremely long time after the harvesting process, which is crucial for the conditions of transport and storage. This hybrid pepper is characterized by high resistance to fruit top rot (spotting).

During the two-year period (Factor A) in the protected area, treatments with microbiological preparations (Factor B) were applied, namely with effective microorganisms (EM-active) and *Trichoderma* sp. (Vital Tricho), which are registered and are on the official list of permitted means for use in organic production in the Republic of Serbia (http://www.uzb.minpolj.gov.rs/attachments/280_LIsta_SIB_organska_24mart2016.pdf).

EM Aktiv is a liquid microbiological concentrate that contains more than 80 selected strains of beneficial microorganisms, predominantly anaerobic and facultatively anaerobic, grown in controlled conditions. Vital Tricho is a biological preparation that contains selected antagonistic strains of fungi of the genus *Trichoderma*. Table 1 shows the treatments that were used in the experiment. An irrigation system was established during planting. Weeds were removed manually and no herbicide was applied in the experiment. No plant diseases or pest attacks were recorded during the research period. Lettuce was grown as a pre-crop in both research years.

Table 1. Application of treatment with microbiological preparations

Method of application	Implementation phase	EM Active	Vital Tricho
Incorporation	During transplanting	1 l/ha in 10 l of water	0.4 g/ha in 10 l of water
Foliar treatment x1	2 weeks after transplanting	2 l/ha in 100 l of water	0.04 g/ha in 100 l of water
Foliar treatment x2	At the beginning of the flowering phase	2 l/ha in 100 l of water	0.04 g/ha in 100 l of water
Foliar treatment x3	In full bloom	2 l/ha in 100 l of water	0.04 g/ha in 100 l of water

Source: Authors' own research.

During the two-year research, temperatures (℃) and relative air humidity (%) were measured three times for both years using a digital thermometer or hygrometer (Type Class 303c, producer: China) (Table 2). The temperature was affected by the temperature of the air outside the greenhouse, as well as the relative humidity of the air, as well as timely ventilation of the greenhouse. The irrigation process and watering rates were the same for each year (approx. 550 l/m ^{2}). The average monthly temperature for the entire vegetation period of pepper in the first year of the experiment was 23.2℃, and in 2017 it was 24.7℃, while the relative humidity was 40.9% , that is, in the second year of the experiment, it was 55.0%. Observed differences in temperature values are the result of cultivation in semi-controlled conditions, in a tall block system of greenhouses, where the examined parameters were additionally influenced by the level of external meteorological conditions.

Table 2. Average values of mean monthly air temperatures (°C) and relative humidity air (%)

Year	Temperatures (°C)						Relative humidity of air (%)					
	April	May	June	July	August	Average	April	May	June	July	August	Sum
And	21.2	22.8	20.8	26.9	24.1	**23.2**	49.0	37.7	38.7	39.6	39.6	**40.9**
II	22.7	24.3	22.2	28.2	25.7	**24.7**	58.1	53.0	54.2	54.9	54.9	**55.0**

Source: Authors' own research.

Harvesting was carried out manually, successively in five periods. The fruits were collected at the stage of technological maturity, when they had a light yellow color. The total yield per area unit (kg/m²) was measured on ten plants from each elementary plot.

Statistical analysis of the data was performed using IBM SPSS Statistics software, version 26.0, IBM Corp., Armonk, NY, USA. The first factor was the year of production (A), and the second factor was the treatment - with microbiological stimulators (B). An analysis of variance (ANOVA) was applied to assess the impact of the factors with significance levels set at $p<0.05$ and $p<0.01$. Tukey's test (HSD - Honestly Significant Difference) was used to compare the mean values between treatments. An interval plot was created in Minitab Statistics Software (Trial version) to show the average values of pepper yield for each treatment combination with a 95% confidence interval and an interaction plot to visualize the relative importance of the various factors affecting the variables and their interactions. The results are presented in tables and graphs.

As part of the economic analysis of peppers production, the method of calculating variable costs (gross margin) was applied. The calculation of the economic parameters was carried out at the level of the greenhouse with an area of 98 m², based on the achieved production results and market prices in the observed production cycle. All relevant variable costs of production were included in the analysis, including the costs of seedlings, fertilizers and biostimulators, plant protection products and the like.

The production value (PV) was calculated as the product of the total realized yield (Q, kg) and the average market price of the product (P, EUR/kg), according to the following relationship:

$$PV = Q \times P$$

Total variable costs (VC) represent the sum of all variable costs included in the production process and are expressed in euros (EUR). Gross margin (GM) is determined as the difference between production value and variable costs, according to the formula:

$$GM = PV - VC$$

The variable production cost per unit of output (CP_v) is calculated as the ratio of total variable costs to the total produced quantity, according to the following expression:

$$CP_v = VC / Q$$

Production profitability (PP) is defined as the ratio of gross margin to variable costs, expressed as a percentage, and is calculated according to the formula:

$$PP = (GM / VC) \times 100$$

The lower breakeven point (BEP) represents the minimum volume of production necessary to cover variable costs and is calculated as the ratio of variable costs to the selling price of the product, according to the formula:

$$BEP = VC / P$$

The applied methodological approach (enables a comprehensive overview of the economic effects of the application of microbial biostimulators in a sustainable system of pepper production, through the analysis of key indicators of production efficiency and stability.

Results and discussions

Pepper is a thermophilic species and has specific requirements for environmental conditions. Optimal growth and expression of genetic yield potential require precisely regulated heat, light and humidity, as well as a continuous supply of readily available nutrients. Due to these demands, protected cultivation in polyethylene and glass greenhouses has become standard practice under the agroecological conditions of the region. Such systems enable partial or complete microclimate control, significantly reducing the risks associated with extreme weather events. A major advantage of protected cultivation is the substantial extension of the growing season, allowing fresh peppers to be available for more than six months annually. Moreover, intensive greenhouse conditions result in considerably higher yields compared to open-field production, ensuring stable market supply.

The conducted two-year research confirms that the application of tested microbiological preparations significantly improves the productivity of the Blondi F_1 pepper hybrid. The results clearly indicate that the influence of year and treatment was statistically highly significant at the level of $p<0.01$ (Table 3). The yield of peppers is influenced by complex relationships between factors and the optimal yield is achieved by combining individual treatments in a given year.

Table 3. Analysis of Variance for Yield of pepper (ANOVA)

Source	SS	MS	F-Value	P-Value
Year	0.2689	0.2689	40.33 **	0.000
Treatment	38.7011	19.3506	2902.58 **	0.000
Year x Treatment	0.3211	0.1606	24.08 **	0.000
Total	39.3711			
CV (%)	0.18			

Source: Authors' own research.

Notes: SS-Sum of squares; MS-Mean Squares; F value calculated - F statistics;
**-Highly significant at $p < 0.01$ probability level; P- Value calculated – p-level, CV- Coefficient of variation.

The total average yield was 19.52 kg/m ^{2} (Figure 1). In the second year of the research, the highest yield was recorded (19.64 kg/m^2), which was higher by 1.23% (19.40 kg/m^2) compared to the first year. On average for both years, the highest yield was in the treatment with the microbiological preparation Vital Tricho (21.52 kg/m^2), which is higher by 19.35% (18.03 kg/m^2)

compared to the control treatment and by 13.15% (19.02 kg/m^2) compared to the treatment where the preparation EM-Aktiv was applied.

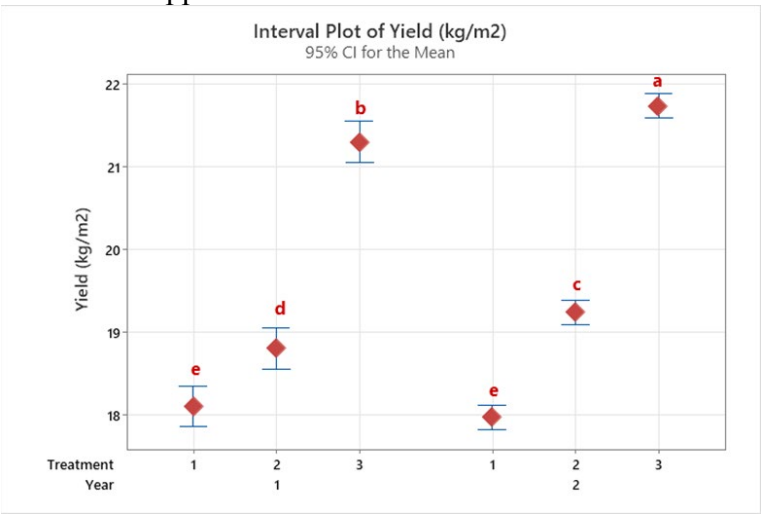


Figure 1. Interval Plot for pepper yield (kg/m ^{2}) with 95% confidence interval for the mean value. Tuckey test - different letters indicate significant differences (p<0.05). Year: 1; 2. Treatment: 1 – Control; 2 – EM Active; 3 – Vital Tricho

Source: Authors' own research.

The analysis of the interaction of the factors of year and treatment (AB) (Table 2) showed a statistically high level of significance in the realized yield. The influence of an individual factor on the yield of pepper fruits depends on the level of another factor, which is shown in Figure 2.

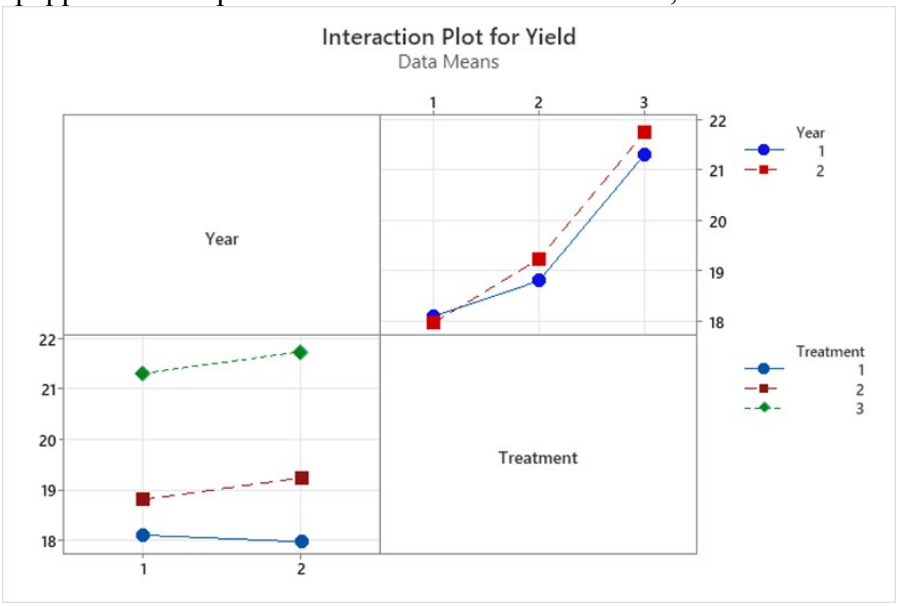


Figure 2. Interaction Plot for pepper yield (effect of factors and mutual interaction). Year: 1; 2. Treatment: 1 – Control; 2 – EM Active; 3 – Vital Tricho

Source: Authors' own research.

Fungi of the genus *Trichoderma* spp. act through multiple mechanisms. They are highly competitive against phytopathogens for space and nutrients and directly attack harmful fungi through mycoparasitism, degrading their cell walls and secreting antimicrobial metabolites. In

addition to their protective role, *Trichoderma* spp. secrete enzymes that increase the solubility of phosphorus and other minerals in the rhizosphere, enhancing their availability to plants. In contrast, effective microorganism (EM) technology is based on a symbiotic community of lactic acid bacteria, photosynthetic bacteria and yeasts, which produce growth hormones, vitamins and enzymes that stimulate cell division and modify soil microbial structure, creating suppressive soil conditions resistant to diseases (Pszczółkowski et al., 2023; Guzmán-Guzmán et al., 2025).

Recent research shows that certain strains of Trichoderma can significantly improve biocontrol against phytopathogenic fungi and at the same time promote the growth and flowering of young pepper plants, which indicates their application as an ecologically acceptable means of sustainable production (Heo et al., 2025).

Application of these biostimulators induces physiological and metabolic changes in pepper plants. By modifying the phytohormone profile and stimulating the synthesis of secondary metabolites, plant resistance to drought, salinity and temperature extremes is enhanced. This is particularly important in intensive greenhouse production, where continuous soil exploitation leads to substrate fatigue and disruption of biological balance. The use of EM and *Trichoderma* preparations revitalizes the rhizosphere, improves nutrient utilization from soil reserves and ensures a high level of fruit quality standardization. For producers, this translates into the potential to achieve premium market prices, as such fruits exhibit better taste, longer shelf life and higher biological value.

The results of the research are correlated with previous research in which it was explained that the application of microbiological preparations, including bacteria of the genus *Bacillus* and fungi of the genus *Trichoderma*, can significantly affect the growth, yield and resistance of peppers (*Capsicum annuum*) in greenhouse conditions (Xiao et al., 2025). Bajagić et al. (2025) confirm in their research that the combined application of EM and *Trichoderma* preparations significantly improves most of the productive properties of peppers, primarily the yield quantity.

Similar effects were recorded using synthetic microbiological communities (SynCom), which stimulate plant resistance and improve fruit metabolism (Bashizi et al., 2025). Biological preparations based on *Trichoderma guizhouense* also showed an increase in nutrient utilization and total pepper yield, while biofertilizers in combination with mycorrhizal fungi increased nutrient absorption and improved plant physiological status (Sini et al., 2024).

EM treatments increased the number of fruits per plant, average fruit weight and total production in some studies compared to controls, especially in combination with organic fertilizers and additional biostimulators. In combination with nitrogen (N), EM increased the number and weight of pepper fruits up to ~28% under saline soil conditions, indicating a synergy of microbes and nutrients under stressful conditions (Abdelkhalik et al., 2022).

The application of EM can also affect the microbiological activity of the soil, which contributes to the improved availability of nutrients and the reduction of pathogens, which indirectly increases the vitality of plants and the quality of fruits. Effective microorganisms can significantly increase enzyme activity and microbiological diversity in soil, including enzymes such as urease, sucrase and peroxidase, which indicates improved microbiological activity of soil after treatment with EM preparations.

The beginning of the 21st century and the implementation of the European Green Deal have established new standards for primary production, focusing on greenhouse gas reduction, biodiversity restoration and high food quality. Microbiological biostimulators represent a key tool in achieving these goals, as they enable a shift from intensive mineral fertilization toward precise, biologically supported nutrition and soil regeneration. In line with the growing importance of

organic production and market demand for safe and healthy food, the integration of biocontrol and biostimulatory agents offers an effective approach to reducing chemical inputs while maintaining productivity and product quality (Xiao et al., 2025). The economic development of this vegetable species is inextricably linked to the system of sustainable agriculture. In this sense, the use of new fertilizers based on natural components ensures that pepper production remains not only high-yielding, but also ecologically justified (Bajagić et al., 2025).

Based on the obtained data on the average pepper yield of 19.52 kg per m^2, ie 6.38 kg per plant, the calculation of the gross margin was calculated based on variable costs for a greenhouse of the same area as in the experiment and with a total of 300 planted pepper plants. The purchase price of peppers was 2.3 EUR/kg.

Table 4. Economic parameters of pepper production (calculation for a 98 m² greenhouse)

Production value (EUR)	Variable costs (EUR)	Gross margin (EUR)	Cost of production (EUR/kg)	Production profitability (%)	Break-even point (kg)
4.072,34	1.104	2.968	0.58	268.72%	518.53

Source: Author's calculation based on average test results.

The results of the economic analysis, based on the average yields obtained from the two-year greenhouse experiment with the application of microbial biostimulants (EM Active and Vital Tricho), indicate extremely favorable economic performance of pepper production in a 98 m² protected cultivation system.. The realized production value of EUR 4.072,34, along with variable costs in the amount of EUR 1.104, resulted in a high gross margin of EUR 2,968, which confirms the extremely favorable relationship between realized income and invested funds (Table 4). The low cost of production of 0.58 EUR/kg indicates efficient use of production inputs and a rational structure of variable costs.

The high level of production profitability (268.72%) indicates that the realized gross margin is multiple times higher than the variable costs, which confirms the high economic justification of the applied cultivation technology. The lower breakeven point, which is 518.53 kg, shows that the minimum required volume of production to cover variable costs, at the current purchase price of peppers, is significantly lower than the realized yield, which indicates a low production risk and a high degree of investment security. These results confirm that the analyzed pepper production system in the protected area provides stable and competitive economic results within sustainable growing systems.

Although intensive and protected cultivation systems ensure high and stable yields, high expenditures on fertilizers, plant protection products, energy and labor limit economic sustainability. Consequently, growing market demand for safe food with a reduced ecological footprint highlights the need for innovative solutions that simultaneously enhance productivity and economic efficiency (Simić et al., 2024). Growing in a protected area (both polyethylene and glass made greenhouses) significantly extends the harvest season, making fresh peppers available on the market for more than six months a year. In addition to continuity of supply, the key advantage of this type of cultivation is the realization of significantly higher yields per area unit compared to production in the open field.

The application of microbial biostimulators represents a technological innovation within sustainable cultivation systems, as it enables a more rational use of resources, improving the efficiency of nutrient utilization and reducing dependence on synthetic agrochemicals (Petrovic et al., 2024). From an economic aspect, such preparations can contribute to the reduction of variable

production costs per unit of product, increase of gross margin and stabilization of financial results, which is of particular importance in conditions of increased uncertainty and price shocks characteristic of the post-pandemic period.

The integration of microbial biostimulators into pepper production represents part of a broader technological transformation of agriculture, in which biologically based innovations enhance the economic and ecological resilience of production systems. Evaluating their application from both agronomic and economic perspectives enables a clearer assessment of their contribution to sustainable agricultural development and improved competitiveness of vegetable production under modern market conditions.

Increasing the yield and quality of fruits directly affects the economic profitability of production. Higher yield and better nutritional quality of fruits (eg higher content of vitamin C, phenolic compounds and antioxidants) enable a higher market price of the product, especially in organic or integrated production systems. Also, biostimulators can increase plant resistance to abiotic stresses (drought, salinity), which stabilizes yield and reduces production risk (Parađiković et al., 2011; Silva et al., 2025).

However, the economic effect is not always unambiguous. There are studies that indicate that the increase in yield is sometimes not statistically significant or does not cover the costs of the preparation, so the economic justification depends on the agroecological conditions, the pepper variety and the method of application of the biostimulator (Majkowska-Gadomska et al. 2021).

From the aspect of agroecology, the research results of biostimulators in pepper can be partially transferred to other ecological production systems, because their action is based on the general physiological mechanisms of plants - stimulation of root growth, better uptake of nutrients and activation of stress responses. Similar positive effects were recorded in other vegetable and field crops, especially in conditions of abiotic stress, which indicates the potential of wide application of these preparations in sustainable agriculture (Bajagic et al., 2024). However, the degree of efficiency can vary significantly due to differences in climatic conditions, soil, cultivation technology and plant genotype, so local adaptation of recommendations is necessary (Abidi et al., 2024; Bajagić et al., 2025).

Overall, the obtained results confirm that microbial biostimulants, particularly *Trichoderma* sp., can provide a dual benefit in organic greenhouse pepper production by simultaneously increasing yield and improving economic performance. The statistically significant yield advantage of the Vital Tricho treatment (21.52 kg/m²) directly translated into higher production value and gross margin, demonstrating that relatively low additional input costs may be compensated through enhanced productivity and reduced unit production costs. From a practical perspective, these findings suggest that the adoption of microbial preparations represents a cost-effective strategy for growers aiming to maintain profitability while reducing dependence on synthetic agrochemicals. Nevertheless, the economic justification of such biostimulants may vary depending on local market prices, cultivar characteristics, and agroecological conditions, indicating the need for further validation across diverse production systems. Despite these limitations, the study provides evidence that microbial-based innovations can strengthen the resilience and competitiveness of sustainable pepper cultivation under protected conditions.

Conclusion

The results of this study indicate that the application of microbial biostimulants in organic and sustainable greenhouse pepper production represents an effective strategy for improving both agronomic productivity and economic performance. The tested preparations, EM Active and Vital

Tricho (*Trichoderma* sp.), significantly enhanced pepper yield, with the Vital Tricho treatment achieving the highest yield increase compared to the control and EM Active. The economic analysis, based on the average outcomes of the two-year protected cultivation experiment, confirmed highly favorable production efficiency, reflected in a high gross margin, low unit production cost, and strong overall profitability. These results suggest that microbial biostimulants can contribute to reducing production risk and improving the competitiveness of sustainable pepper cultivation systems by lowering dependence on conventional agrochemical inputs. From a practical perspective, the adoption of microbial preparations may represent a cost-effective technological option for growers aiming to maintain stable economic returns while meeting increasing environmental and market demands for sustainable production. However, since the experiment was conducted under specific protected conditions and with one hybrid, further research across different agroecological environments and production systems is recommended to support broader transferability of the findings. Overall, microbial-based innovations such as EM Active and *Trichoderma* sp. offer promising potential for strengthening the resilience and long-term sustainability of intensive vegetable production.

Acknowledgement

This paper was co-financed by The Bucharest University of Economic Studies during the PhD program.

References

Abdelkhalik A., Abd El-Mageed TA, Mohamed IAA, Semida WM, Al-Elwany OAAI, Ibrahim IM, Hemida KA, El-Saadony MT, AbuQamar SF, El-Tarabily KA, & Gyushi MAH (2022). Soil application of effective microorganisms and nitrogen alleviates salt stress in hot pepper (*Capsicum annum* L.) plants. *Front Plant Sci*. 2023 Jan 18; 13:1079260. doi: 10.3389/fpls.2022.1079260. PMID: 36743545; PMCID: PMC9889995.

Abidi, S., Tallarita, A. V., Cozzolino, E., Stoleru, V., Murariu, O. C., Abidi, A., ... & Balti, R. (2024). Biostimulant Effects of Algae Species, Arbuscular Mycorrhizal Fungi, and Their Combinations on Yield and Quality of Yellow Tomato Landrace Under Different Crop Cycles. Horticulturae, 10(8), 876. https://doi.org/10.17660/ActaHortic.2025.1416.28

Avasiloaiei D.I., Brezeanu C., Bălăiță C., Antal-Tremurici A., & Calara, M. (2024). Evaluating the efficiency of using biostimulants for sweet pepper seedlings production (*Capsicum annuum* L. var. *grossum*) in an organic system. In EHC2024: International Symposium on Sustainable Vegetable Production from Seed to Health Booster Sources 1416, pp. 149-156, https://doi.org/10.17660/ActaHortic.2025.1416.20

Bajagic M., Cvijanovic G., Blagojevic M. (2024): In the production of healthy safe food for the needs of the development of sustainable rural tourism, Book of Proceedings, Second International Conference GIRR 2024, Šabac, 10th May, 2024, pp. 132-141, https://fiver.ifvcns.rs/bitstream/id/12380/bitstream_12380.pdf

Bajagić M., Đukić V., Miladinov Mamlić Z., Sekulić J., Cvijanović V., Đurić N., & Cvijanović G (2023): Effect of pulsed electromagnetic field on yield of grain, yield of protein and oil of soybean, *Plant Soil Environ*, Vol. 69, No. (12): 577–585 DOI: 10.17221/336/2023-PSE

Bajagić M., Šević B., Daw E., Cvijanović V., Sekulić J., Ivetić A., & Cvijanović G. (2025). Improvement of qualitative components and yield with the contribution of biological fertilizers in organic pepper production. *Applied Ecology and Environmental Research*, 23(5), 8621-8638. https://aloki.hu/indvol23_5.htm

Bashizi TF, Kim MJ, Lim K, Lee G, Tagele SB, & Shin JH (2025). Application of a Synthetic Microbial Community to Enhance Pepper Resistance Against *Phytophthora capsici*. *Plants* (Basel). May 26;14(11):1625. doi: 10.3390/plants14111625. PMID: 40508300; PMCID: PMC12157186.

Guzmán-Guzmán, P., Etesami, H. & Santoyo, G. (2025). *Trichoderma:* a multifunctional agent in plant health and microbiome interactions. *BMC Microbiol* 25, 434 https://doi.org/10.1186/s12866-025-04158-2

Heo Y, Han G, Moon HY, Lee CS, & Cheon W. (2025). Biocontrol Potential and Growth-Promoting Effects of Freshwater *Trichoderma* Strains against Plant Pathogenic Fungi in Red Pepper. *Plant Pathol J* . 2025 Jun;41(3):392-408. doi: 10.5423/PPJ.OA.02.2025.0019. Epub 2025 Jun 1. PMID: 40468885; PMCID: PMC12146629.

Majkowska-Gadomska, J., Dobrowolski, A., Jadwisieńczak, K.K. Kaliniewicz Z., & Francke A. (2021). Effect of biostimulants on the growth, yield and nutritional value of *Capsicum annuum* grown in an unheated plastic tunnel. *Sci Rep* 11, 22335 https://doi.org/10.1038/s41598-021-01834-x

Parađiković N, Vinković T, Vinković Vrček I, Žuntar I, Bojić M, Medić-Šarić M. Effect of natural biostimulants on yield and nutritional quality: an example of sweet yellow pepper (*Capsicum annuum* L.) plants. *J Sci Food Agric*. 2011 Sep;91(12):2146-52. doi: 10.1002/jsfa.4431.

Petrović, M. , Savić, B., Cvijanović, V. (2021): Financial aspects of pepper (Capsicum annuum L) production on family farms in Serbia, Economic of Agriculture, Institute of Agricultural Economics, Belgrade, 68 (4): 1015-1028, https://doi.org/10.5937/ekoPolj2104015P , UDC 338.314:635.649 (497.11).

Petrović, M., Marina, I., Jelocnik, M. (2024): The significance and role of using innovative technologies in modern agricultural production, Journal of Research and Innovation for Sustainable Society (JRISS), 6 (2): 289-303. https://doi.org/10.33727/jriss.2024.2.32:289-303

Pszczółkowski, P., Sawicka, B., Barbaś, P., Skiba, D,. & Krochmal-Marczak, B. (2023). The use of effective microorganisms as a sustainable alternative to improve the quality of potatoes in food processing. *Applied Sciences* . 13(12). 7062. https://doi.org/10.3390/app13127062

Rajić, Z., Ljiljanić, N., Petrović, M. (2023): Production and economic aspects of vegetable production in the Republic of Serbia, Book of Proceedings, Scientific symposium with international participation "Agribusiness, Food and Rural Areas - Perspectives and Challenges of Agenda 4.0.", 21.-22. September 2023, Faculty of Agriculture, University of Belgrade, pp. 240 – 250, ISBN 978-86-7834-424-4.

Šević B., Dolijanović Ž., Bajagić M., Rajicić V., Tupajić I., Cvijanović V., & Stojiljković J. (2025). Cover crops as a tool for improving the nutritional properties and antioxidant activity of kernel sweet corn, *Romanian Agricultural Research*, No. 42, DII 2067-5720 RAR 2025-199, pp. 883-894. https://new.incda-fundulea.ro/images/rar/nr42/rar42.75.pdf

Silva A.L.J., de Farias O.R., Corrêa É.B. de Lacerda C.F., de Melo A.S., de Mello Oliveira M.D. (2025). Biostimulant modulate the physiological and biochemical activities, improving agronomic characteristics of bell pepper plants under salt stress. *Sci Rep* 15, 14969 https://doi.org/10.1038/s41598-025-99414-w

Simić, D., Popović, V., Janković, S., Petrović, M. , Tolimir, N., Stanković, S., Nikolić, D. (2024): Production of safe food with preservation of resources, VII International Scientific Conference " Village and Agriculture", Požarevac, Serbia, Book of Proceedings, 27-29. September, 2024, pp. 271-279, ISBN 978-99976-054-0-5.

Sini, HN, Barzegar, R., Mashaee, SS, Ghahsare, MG, Mousavi-Fard, S., & Mozafarian, M. (2024). Effects of biofertilizer on the production of bell pepper (*Capsicum annuum* L.) in greenhouse. *Journal of Agriculture and Food Research*, *16*, 101060. https://doi.org/10.1016/j.jafr.2024.101060

Xiao, M., Liu, X., Wang, X., Lu, W., Zhang, T., & Yang, Y. (2025). Microbial inoculants drive disease suppression and rhizosphere modulation for effective management of pepper phytophthora blight. *Applied Soil Ecology*, *208*, 105971. https://doi.org/10.1016/j.apsoil.2025.105971