AGRONOMY SCIENCE

Online first 2026

https://doi.org/10.24326/as.2026.5737

RAFAŁ WNUCZEK[1], ANNA NOWAK[2], WOJCIECH BISZCZAK[3],

MAŁGORZATA HALINIARZ[4]

Economic and production performance of maize under integrated biological agent applications. A three-year field study

Abstract. The aim of this study was to evaluate the production and economic performance of different maize cultivation treatments, differing in the intensity of biological agent application. A field experiment (3 years) was conducted in 2023–2025, in a split-block design with three replications. The experimental factors included seven combinations of biological agent doses applied in maize cultivation. The results demonstrated that these preparations increased maize grain yield, with most beneficial effects observed when several agents with different modes of action were applied simultaneously. In each study year, the highest income was generated by the treatment with two preparations (microbiological and metabolic) applied at full doses. Although this treatment proved the most costly, it significantly enhanced maize productivity. The yield increase compared to the control treatment ranged from 19% to 27% in the studied years, making this treatment more profitable. In agricultural practice, it is advisable to consider the full-dose combination of microbiological and metabolic preparations or, alternatively, a reduced-dose treatment as a compromise solution merging high profitability with lower input costs, when aiming to maximize economic returns. In light of the results, it is clear that integrating biological agents in maize cultivation technology is an effective and economically justified solution that should be more widely recommended in agricultural practice to support sustainable crop production.

Keywords: maize, biostimulants, yield performance, economic efficiency, profitability index, biostimulant synergy

INTRODUCTION

Common maize (*Zea mays L.)* is a cultivated plant of the *Poaceae* family. It is an annual spring cereal classified as a short-day plant. Its high-yielding potential is due to numerous favorable physiological and morphological traits of this species. However, it is noteworthy that its yield performance is strongly influenced by weather conditions during individual growing seasons as well as by local environmental conditions [Skwarek and Pipiak 2020, Król-Badziak et al. 2024]. Maitah et al. [2021] and

[1] Department of Economics and Agribusiness, Faculty of Agrobioengineering, University of Life Sciences in Lublin, 13 Akademicka Street, 20-950 Lublin, Poland, https://orcid.org/0009-0002-2767-4614
[2] Department of Economics and Agribusiness, Faculty of Agrobioengineering, University of Life Sciences in Lublin, 13 Akademicka Street, 20-950 Lublin, Poland, https://orcid.org/0000-0003-1741-8692; corresponding author: anna.nowak@up.edu.pl
[3] Department of Herbology and Plant Cultivation Techniques, Faculty of Agrobioengineering, University of Life Sciences in Lublin, 13 Akademicka Street, 20-950 Lublin, Poland, https://orcid.org/0000-0002-7666-0748
[4] Department of Herbology and Plant Cultivation Techniques, Faculty of Agrobioengineering, University of Life Sciences in Lublin, 13 Akademicka Street, 20-950 Lublin, Poland, https://orcid.org/0000-0001-7363-9452

© Copyright by the Authors, 2026

Licensee University of Life Sciences in Lublin – Publishing House, Lublin, Poland
This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution 4.0 International license.

Wang [2025] emphasized that, although other factors (e.g., soil fertility, crop management practices, insect pressure, diseases, and weeds) may affect maize production, fluctuations in temperature and changes in precipitation patterns associated with climate change, including in particular heat stress and drought, pose serious challenges to its growth.

The importance of these determinants and the selection of appropriate production technologies is particularly significant in the context of maize's role in ensuring global food security [Miedaner and Juroszek 2021, Grote et al. 2021, Csorba 2024]. In the European Union, maize is the second most widely cultivated crop after wheat. According to FAOSTAT data [2026], the global maize cultivation area in 2024 amounted to 209.95 million hectares, of which 4.1% was located in the European Union (8.7 million ha). Global production reached 1,218.2 million tonnes, while the EU produced 58.9 million tonnes of maize grain (4.8%). The average grain yield in the EU was 6,794.6 kg·ha^{-1}, compared with the global average of 5,802.2 kg·ha^{-1}. Compared with wheat and rice, maize is a more versatile crop with multiple applications [Erenstein et al. 2022, Datsko et al. 2024, Wang and Zhang 2024]. Despite its relatively high productivity, maize cultivation remains highly vulnerable to adverse environmental factors, particularly water deficit, which prompts producers to seek solutions that enhance yield stability [Sárvári and Pepó 2014]. In this context, biostimulants and soil-improving products are increasingly applied to improve both plant condition and environmental resource-use efficiency [Piati et al. 2023, Sobiech et al. 2025]. These substances support root system development, increase photosynthetic activity, improve nutrient uptake, and enhance plant tolerance to abiotic stresses, such as drought, high temperatures, or soil salinity. Consequently, their use may contribute to improved plant growth and yield stabilization under variable environmental conditions. Biological agents that support soil fertility also play a significant role in modern crop production systems, including microbiological preparations containing beneficial soil bacteria and fungi. These microorganisms participate in the mineralization of organic matter, increase the availability of nutrients for plants, and improve soil structure and the biological activity of the soil environment. The introduction of such solutions aligns with the concept of sustainable agriculture, which seeks to reduce environmental pressure while maintaining high crop productivity. In addition to addressing environmental considerations in line with contemporary agricultural development trends, cultivation technologies must also remain economically viable for agricultural producers [Panoutsou and Alexopoulou 2020].

Production profitability poses a key decision-making challenge in modern agriculture, especially amid increasing input price volatility, cost pressures, and tightening environmental regulations [Wnuczek et al. 2026]. The profitability of maize cultivation is determined by the relationship between yield performance, input levels, and market conditions [Niewęgłowski et al. 2020]. Agricultural production systems are dynamic and evolve over time. The development and dissemination of new production technologies are regarded as effective means of improving agricultural productivity and increasing farmers' incomes [Ruzzante et al. 2021, Amaya-Pérez et al. 2022]. At the same time, science and innovation are crucial components of transforming agriculture toward sustainability, aimed at reducing environmental pressure, including greenhouse gas emissions, soil degradation, and water pollution [Gaffney et al. 2019, FAO 2026]. In this context, environmentally-friendly production technologies consistent with the objectives of the European Green Deal and the "Farm to Fork" strategy are gaining particular importance [European Commission 2020]. These challenges can be addressed by implementing precision agriculture solutions, the biologicalization of production, and the use of innovative plant growth-promoting products, such as biostimulants [Ocwa et al. 2024]. The importance of this group of products has been formally recognized in EU legislation, including Regulation (EU) 2019/1009 of the European Parliament and of the Council [2019], laying down the rules on the making available on the EU market fertilizing products, including biostimulants.

Despite the dynamic development of research on the effects of biostimulants and biological agents on maize growth, yield performance, and tolerance to abiotic stresses, including water deficit, research continues to focus predominantly on their biological and yield-related effects [Du Jardin 2015, Calia 2025, Sobiech 2025]. In particular, short-term and single-factor analyses predominate, which, however, fail to reflect the complexity of production decisions made in agricultural practice. Comprehensive assessments of their economic performance – taking into account various doses and coupled application within alternative maize production technologies – are undertaken far less frequently [Niewęgłowski et al. 2020]. Also, there is a paucity of long-term studies that merge production and economic aspects under varying market and environmental conditions. Available economic studies most often refer to simplified comparisons (conventional technology vs alternative technology) or analyze single plant growth promoters, neglecting variability in application intensity and interactions between biological preparations and input levels [Panoutsou and Alexopoulou 2020, Ruzzante et al. 2021, Ocwa et al. 2024]. This limitation hinders the identification of optimal management strategies for biological agents from an economic perspective. Consequently, there is a lack of explicit evidence to assess whether reducing biostimulant doses or combining them may improve economic efficiency, understood as the relationship between production value and incurred costs. This research gap becomes particularly significant under conditions of increasing input price volatility and pressure to reduce mineral fertilization [European Commission 2020]. From the farmers' perspective, it is therefore crucial not only whether a given technology increases yield, but also whether and to what extent it improves the farm's economic outcome, particularly compared with the control technology. Hence, a clear need emerges for research combining an experimental approach (multi-year field trials) with an in-depth analysis of the economic efficiency of various application variants of biological preparations.

The aim of the study was, therefore, to evaluate the production and economic performance of different maize cultivation treatments, involving varying levels of biological agent application intensity. Specifically, it evaluated the impact of different combinations of biological agents on maize yield levels and, subsequently, on the resulting economic outcomes. Study findings were expected to enable determining whether alternative production technologies based on biological products may constitute an economically justified solution to cost pressures and environmental requirements in contemporary agriculture.

MATERIALS AND METHODS

Location and experiment design

The study was conducted at the Experimental Farm of the University of Life Sciences in Lublin, located in Czesławice, Poland (51°18'23"N, 22°16'2"E). The experiment was established on Haplic Luvisol developed from loess, classified as quality class II, in a split-block design with three replications. Individual experimental plots measured 4.5 × 10 m. The soil from the plot prepared for maize sowing was analyzed for its mineral composition. It had a moderate content of mineral nitrogen ($N\text{-}NO_3$ – 18.02 mg kg^{-1}, $N\text{-}NH_4$ – 1.4 mg kg^{-1}), was very rich in phosphorus (P_2O_5 – 395 mg kg^{-1}), rich in potassium (K_2O – 220 mg kg^{-1}) and sulfur ($S\text{-}SO_4$ – 202 mg kg^{-1}), and also had a low level of magnesium (Mg – 35 mg kg^{-1}). Contents of microelements in the soil were moderate, except for boron, the content of which was low (B – 1.03 mg kg^{-1}). Low organic carbon content was also observed, reaching 7.8g kg^{-1} d.m., while soil pH_{KCl} was 6.1.

The test crop was maize (*Zea mays* L.), cultivar RGT Bernaxx, entered into the Polish National Register of Varieties (COBORU) on the 13th of March 2020. It is an early-maturing cultivar (FAO 230), intended for grain production, characterized by high tolerance to water stress, rapid grain drying, and suitability for cultivation in both poorer and more fertile soils. The sowing density was established at 80,000 seeds ha^{-1}. Winter wheat served as the previous crop.

The objective of the experiment was to assess the effect of biological preparations on maize yield over the period 2023–2025. Two products were applied:

1. Novobakt Azofosfo – a 100% bacteria-based biological preparation containing strains capable of fixing atmospheric and soil nitrogen and increasing phosphorus availability (*Azospirillum lipoferum*, *Azotobacter chroococcum*, and *Bacillus megaterium*). It also stimulates plant growth, resulting in enhanced root system development and above-ground biomass production.

2. Microspeed Energy – a specialized fertilizer classified as a biostimulant. It accelerates plant regeneration, enhances nitrogen-use efficiency, prolongs plant photosynthetic activity, and inhibits chlorophyll degradation under drought and high-temperature conditions. Its composition is as follows: 2 g dm^{-3} of CDI (chlorophyll degradation inhibitor; 1-(2-methoxyethyl)-3-(1,2,3-thiadiazol-5-yl) urea), 320 g dm^{-3} of pyroglutamic (pidolic) acid, 33.3% of organic matter, 35% of dry matter, 3.4% of total nitrogen (N), 3.4% of urea nitrogen ($N\text{-}NH_2$), 0.4% of phosphorus (P) soluble in mineral acids, and 2% of potassium oxide (K_2O) soluble in water.

Seven treatment combinations were established and designated as follows:

A – Novobakt Azofosfo at a full dose (250 g ha^{-1}),

B – Microspeed Energy at a full dose (250 mL ha^{-1}),

C – Novobakt Azofosfo at 75% of the full dose,

D – Microspeed Energy at 75% of the full dose,

E – Novobakt Azofosfo (full dose) + Microspeed Energy (full dose),

F – Novobakt Azofosfo (75% of the full dose) + Microspeed Energy (75% of the full dose),

G – control without microbiological preparations.

Maize was cultivated in the conventional plough-based system. The same cultivation technology and terms of agrotechnical measures were applied in each study year. In the autumn, a potassium fertilizer (90 kg K ha^{-1} as potassium salt) was applied, followed by winter ploughing to a depth of 25 cm, and subsequently harrowing performed in the spring. Two weeks prior to the planned sowing date, a nitrogen fertilizer was applied at a rate of 124.2 kg N ha^{-1} (urea). In all study years, maize was sown between the 25th and 30th of April. Soil was prepared using a cultivation aggregate to a depth of 5 cm, followed by precision sowing with simultaneous application of a phosphate fertilizer at 46 kg P ha^{-1} and 18 kg N ha^{-1}. Maize was sown in six rows on each plot. After emergence (BBCH 12-18 – according to the international BBCH scale of plant developmental stages, from the emergence of 2 true leaves to 8 true leaves), the Elumis 105 OD herbicide (mesotrione + nicosulfuron) was applied at a rate of 1.5 dm^3 ha^{-1}. Biological preparations were applied at BBCH 13-18 (the growth stage from 3 to 8 leaves). In all three study years, maize was harvested between the 20th and 30th of October. Ten maize plants were collected from each experimental plot. To avoid edge effects, 10 plants were selected from different parts of the plot, from the four central rows. Kernels were separated from the cobs using a manual threshing machine, weighed, and the results were converted per 1 ha based on the previously determined plant density.

During the maize growing season (April–September), total precipitation in the years 2023–2025 in the Czesławice area (Lublin Voivodeship) differed from the long-term average for 1991–2020, which was approximately 430 mm. In 2023, the total precipitation approximated 445 mm and was close to the long-term average. Precipitation in April was below normal. In 2024, the total precipita-

tion reached approximately 480 mm, exceeding the long-term average. Precipitation recorded in June was significantly above the multi-year norm, while spring precipitation was close to the average levels. In 2025, the total precipitation was lower, reaching about 380 mm. The greatest deficits occurred in June and July, whereas the heaviest rainfall was recorded in September.

The average air temperature during the maize growing season was higher than the long-term average of approximately 13.5°C. In 2023, the average air temperature was approx. 14.6°C, with July being the warmest month (approx. 19.5°C). In 2024, it reached around 15.0°C; with August recorded as the warmest month with an average temperature (approx. 20.2°C) substantially above the long-term norm (18.5°C). In 2025, the average air temperature was approx. 14.7°C, with the highest values recorded in July (20.0°C) and August (19.8°C). The meteorological conditions in 2023–2025 indicate a clear warming trend compared to long-term averages, along with variability in precipitation.

Statistical analysis of yield

The study results collected over the period of 2023–2025 were processed using the analysis of variance (ANOVA), and the significance of differences was estimated using Tukey's test at a significance level of $p \leq 0.05$. The effects of biological treatments on grain yield in each year were analyzed separately. Standard deviation (SD) was additionally calculated for grain yield. Calculations were made using Statistica 14.0.0 software (TIBCO Software Inc., Tulsa, OK, USA).

Economic efficiency

Generally, farmers have limited influence on agricultural product prices. However, they may analyze ongoing changes, adjust production technologies, and make appropriate management decisions, the effectiveness of which largely depends on their knowledge. Production costs play a crucial role in determining the final financial result (income); hence, continuous monitoring of production profitability is necessary [Skarżyńska et al. 2022]. The study's time span enabled analysis of the economic performance of individual cultivation treatments under varying weather and market conditions. Economic categories consistent with the EU cost-accounting framework used in the Farm Sustainability Data Network (FSDN) system were used to accomplish the study objective. The main economic indicators included gross margin and income from activity. Gross margin was defined as annual income per 1 hectare minus direct costs, whereas income from activity was defined as the production value minus total production costs and as the income from activities plus subsidies [Skarżyńska 2021]. The mentioned economic indicators were computed using the following formulas:

$$\text{Gross margin} = \text{production value} - \text{direct costs} \quad (1)$$

$$\text{Income from activity} = \text{production value} - \text{total costs (direct and indirect in total)} \quad (2)$$

$$\text{Income from activities with subsidies} = \text{income from activities} + \text{subsidies} \quad (3)$$

According to the adopted methodology, the above-mentioned economic categories are computed per 1 ha of crops [Skarżyńska 2021]. The analysis was extended by selected economic efficiency indicators:

1) unit cost of production of 1 dt of grain [EUR dt^{-1}],
2) total production value per 1 EUR of direct costs [EUR],
3) gross margin per 1 dt of the main product [EUR dt^{-1}].

The profitability index (PI) was also calculated as the ratio of production value per hectare to total costs, according to formula (4):

$$PI = \frac{P}{C} \times 100\% \quad (4)$$

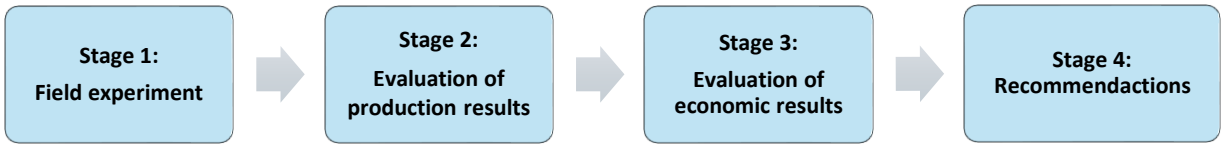
where:
PI – profitability index,
PV – production value,
C – total costs.

A PI value above 100% indicates that the production value exceeds total production costs, and thus the activity is economically profitable.

The economic analysis was conducted relative to the average yield for each cultivation treatment. The maize grain sale price adopted in the analysis corresponded to the average market price in a given season (EUR 92.51 t^{-1} in 2023; EUR 117.44 t^{-1} in 2024; EUR 103.77 t^{-1} in 2025). Prices and the value of production were converted from PLN to EUR using the annual weighted average exchange rates of the National Bank of Poland (NBP).

In order to compare the value of production and the other output categories between cultivation treatments, relative differences (%) were calculated for each treatment compared to the control treatment for the analyzed indicator. This approach also enabled the identification of treatments with the highest and lowest economic efficiency. In turn, ranking the production value and income of individual cultivation treatments within each study year enabled assessment of the stability of results in 2023–2025. It was assumed in the analysis that the smaller the difference between the highest and the lowest rank of a given treatment in the analyzed years, the greater its production stability. Figure 1 presents the stages of the research process described above.

Figure 1. Stages of the research process



RESULTS

Grain yield and production value

Differences in grain yield were observed among the individual treatments of biological agent application, which significantly affected the production value (Table 1). The treatments producing the highest yields were those combining the two biological preparations, i.e., Microspeed Energy and Novobakt Azofosfo, at full doses (E). In 2023-2025, the grain yield produced in this cultivation treatment was from 19.3% to 27.7% higher compared to the control treatment. Noteworthy is that, in this treatment, the highest yields were achieved in all study years and that the values of standard deviation (SD), particularly those computed in the first and last year of the study, indicate high stability of maize yielding upon the use of Microspeed Energy and Novobakt Azofosfo, at full doses. The second-best performance in terms of grain yield was observed with both preparations applied at reduced rates (75% of the full dose), whereas the lowest grain yield was recorded in the control treatment. In this case, the grain yield exceeded the yield produced in the control treatment by 11.7% (2025) to

19.6% (2024). However, the yields obtained on plot F did not differ significantly from those recorded in the remaining plots (i.e., experimental treatments) in each study year. These findings indicate the effectiveness of the analyzed preparations and support their use as means for maximizing maize yield. The grain yield level directly determines the production value per hectare. The maize production value varied as affected by cultivation treatment and study years, but still the highest value was computed in each year for treatment E, with the mean value reaching 1.328.6 EUR ha^{-1}, i.e., being 23.7% higher than in the control treatment. A high production value was also noted in treatment F, whereas the other treatments ensured a moderate increase in the production value compared to the control, suggesting a positive, though varied, effect of the applied biological agents (Table 2).

Table 1. Maize grain yield (dt ha^{-1}) in 2023–2025

Cultivation treatment*	Grain yield (dt)		
	2023	2024	2025
A	111.9^{ab}** ±9.2***	107.0^{ab} ±10.4	113.3^{ab} ±3.8
B	102.2^{ab} ±8.6	104.2^{b} ±12.0	114.0^{ab} ±9.3
C	111.0^{ab} ±6.0	103.3^{b} ±2.0	115.0^{ab} ±2.3
D	103.7^{ab} ±9.7	119.6^{ab} ±5.7	106.5^{b} ±5.6
E	128.3^{a} ±4.5	127.0^{a} ±8.6	126.0^{a} ±1.9
F	115.0^{ab} ±4.6	122.0^{ab} ±7.1	118.0^{ab} ±4.8
G	100.5^{b} ±8.5	102.0^{b} ±7.0	105.6^{b} ±10.1

Notes: *Cultivation treatment: A – Novobakt Azofosfo at a full dose, B – Microspeed Energy at a full dose, C – Novobakt Azofosfo at 75% of the full dose, D – Microspeed Energy at 75% of the full dose, E – Novobakt Azofosfo (full dose) + Microspeed Energy (full dose), F – Novobakt Azofosfo (75% of the full dose) + Microspeed Energy (75% of the full dose). **Different letters denote significant differences ($p \leq 0.05$). The same letter means not significantly different values ($p \leq 0.05$). ***Standard deviation (SD).

Table 2. Maize production value (EUR ha^{-1}) in 2023–2025

Cultivation treatment*	2023	2024	2025	Average 2023–2025 (EUR ha^{-1})	Ratio of the average to the control variant (%)
	production value (EUR·ha^{-1})				
A	1035.2	1256.6	1175.8	1155.9	107.6
B	945.5	1223.7	1183.0	1117.4	104.0
C	1026.9	1213.2	1193.4	1144.5	106.5
D	959.3	1404.6	1105.2	1156.4	107.6
E	1186.9	1491.5	1307.5	1328.6	123.7
F	1063.9	1432.8	1224.5	1240.4	115.4
G	929.7	1197.9	1095.8	1074.5	100.0

Notes: * Symbols are as in Table 1.

The rankings of individual cultivation treatments in terms of their production value enable concluding that treatment E held the most stable position over the analyzed period and consistently was ranked first in all study years. Treatment F also demonstrated high stability, whereas the remaining treatments showed greater fluctuations in ranking positions over the years, indicating greater susceptibility to variable production conditions (Table 3).

Table 3. Ranking of cultivation treatments by production value and their variability in 2023–2025

Cultivation treatment*	2023	2024	2025	Rank variability
	ranking by production value			
A	3	4	5	2
B	6	5	4	2
C	4	6	3	3
D	5	3	6	3
E	1	1	1	0
F	2	2	2	0
G	7	7	7	0

Notes: * Symbols are as in Table 1.

Maize production costs

Maize production costs in individual study years and treatments were primarily influenced by the combinations of microbiological preparations applied, with the remaining elements of the production technology remaining unchanged. Based on the data presented in Tables 4, 5, and 6, it can be concluded that the highest costs were generated by the application of two preparations at full doses, averaging EUR 58.9 ha^{-1} over the study period. The lowest production cost was associated with the reduced (75%) dose of Novobakt Azofosfo, with an average treatment cost of EUR 23.8 ha^{-1}, whereas the full dose of this preparation resulted in costs of EUR 29.4 ha^{-1}. In turn, the cost of applying Microspeed Energy at the full dose was EUR 29.6 ha^{-1}. The remaining maize production costs did not differ between treatments. Fertilization accounted for the largest share of the total cost structure, while fuel and seed material also had a significant impact on the total production costs. A substantial decline in fertilizer prices was observed between 2023 and 2024, leading to a 13.7% reduction in fertilization costs. In the following year, these differences were no longer significant. Other production costs remained relatively stable over the study period. Although a slight increase in certain input prices was noted, it did not have a meaningful impact on the total production costs.

Table 4. Production costs per 1 ha of maize in 2023

Cultivation treatment*	Production costs (EUR ha^{-1}) in 2023							
	direct costs				total direct costs	indirect costs		total costs
	seed material	plant protection	biological preparations	fertilization		fuel	agricultural tax	
A	179.4	46.3	28.2	340.7	594.6	136.6	24.7	755.9
B	179.4	46.3	28.6	340.7	595.0	136.6	24.7	756.3
C	179.4	46.3	21.2	340.7	587.6	136.6	24.7	748.8
D	179.4	46.3	21.5	340.7	587.9	136.6	24.7	749.1
E	179.4	46.3	56.9	340.7	623.3	136.6	24.7	784.5
F	179.4	46.3	42.7	340.7	609.1	136.6	24.7	770.3
G	179.4	46.3	0.0	340.7	566.4	136.6	24.7	727.6

Notes: *Symbols are as in Table 1.

Table 5. Production costs per 1 ha of maize in 2024

Cultivation treatment*	Production costs (EUR ha^{-1}) in 2024							
	direct costs				total direct costs	indirect costs		total costs
	seed material	plant protection	biological preparations	fertilization		fuel	agricultural tax	
A	186.8	48.1	29.7	294.0	558.6	148.1	26.0	732.8
B	186.8	48.1	29.5	294.0	558.5	148.1	26.0	732.7
C	186.8	48.1	22.2	294.0	551.2	148.1	26.0	725.4
D	186.8	48.1	21.5	294.0	550.4	148.1	26.0	724.6
E	186.8	48.1	59.2	294.0	588.1	148.1	26.0	762.3
F	186.8	48.1	44.4	294.0	573.3	148.1	26.0	747.5
G	186.8	48.1	0.0	294.0	529.0	148.1	26.0	703.1

Notes: * Symbols are as in Table 1.

Table 6. Production costs per 1 ha of maize in 2025

Cultivation treatment*	Production costs (EUR ha^{-1}) in 2025							
	direct costs				total direct costs	indirect costs		total costs
	seed material	plant protection	biological preparations	fertilization		fuel	agricultural tax	
A	192.5	51.3	30.2	296.5	570.4	142.7	26.4	739.5
B	192.5	51.3	30.7	296.5	570.9	142.7	26.4	740.0
C	192.5	51.3	22.6	296.5	562.9	142.7	26.4	732.0
D	192.5	51.3	23.0	296.5	563.2	142.7	26.4	732.3
E	192.5	51.3	60.8	296.5	601.1	142.7	26.4	770.2
F	192.5	51.3	45.6	296.5	585.9	142.7	26.4	755.0
G	192.5	51.3	0.0	296.5	540.2	142.7	26.4	709.3

Notes: * Symbols are as in Table 1.

Gross margin and income

The highest income in each year of the study was generated by treatment E (both preparations applied at full doses). In 2023, the income amounted to EUR 671.8; in 2024, it increased to EUR 973.4; and in 2025, it reached EUR 790.6 (Table 7). Although this treatment was the most cost-intensive, it significantly increased the maize yield. This resulted in a high income. On average, the income from this treatment in individual study years was 31.7% higher than in the control treatment. The highest incomes were recorded in 2024, whereas the lowest ones were in 2023. These fluctuations were largely influenced by changes in the market prices of maize grain. In 2023, the control treatment (G) generated a higher income than treatment B; in 2024, higher than treatments C and B; and in 2025, higher than treatment D, despite no amendment with the biological preparations.

Given the rankings of individual treatments across the studied years, it can be concluded that treatment E achieved the highest and the most stable income position throughout the entire study period, consistently ranking first in all years (no rank variability). Treatment F also exhibited very high stability, consistently ranking second. The remaining treatments showed greater income variability.

The largest fluctuations in rank were observed for treatments C and D, indicating their greater sensitivity to changing conditions throughout the study years (Table 8).

Table 7. Gross margin and income from maize cultivation in 2023-2025 (EUR ha^{-1})

Cultivation treatment*	2023	2024	2025	Average 2023–2025	Ratio of the average to the control variant (%)
	gross margin (EUR ha^{-1})				
A	440.6	698.0	605.3	581.3	109.8
B	350.4	665.3	612.1	542.6	102.5
C	439.3	662.0	630.5	577.3	109.1
D	371.5	853.5	542.0	589.0	111.3
E	563.6	903.4	706.5	724.5	136.9
F	454.8	859.4	638.7	651.0	123.0
G	363.3	669.0	555.6	529.3	100.0
	Income with subsidies (EUR ha^{-1})				
A	548.7	768.0	689.5	668.7	108.4
B	458.6	735.2	696.3	630.0	102.2
C	547.4	732.0	714.7	664.7	107.8
D	479.6	923.5	626.1	676.4	109.7
E	671.8	973.4	790.6	811.9	131.7
F	562.9	929.4	722.8	738.4	119.7
G	471.5	738.9	639.8	616.7	100.0

Notes: * Symbols are as in Table 1.

Table 8. Ranking of cultivation treatments by income and their variability in 2023–2025

Cultivation treatment*	2023	2024	2025	Rank variability
	ranking by income with subsidies			
A	4	4	5	1
B	3	6	4	3
C	5	7	3	4
D	6	3	7	4
E	1	1	1	0
F	2	2	2	0
G	7	5	6	2

Notes: * Symbols are as in Table 1.

The next stage of the analysis involved calculating economic efficiency indicators for the individual cultivation treatments (Tables 9 and 10). In most study years, the lowest unit costs of maize production were recorded for treatment E (combined application of microbiological and metabolic biostimulants at 100% rates). This finding suggests that the combined technology not only generated the highest income but also enabled the lowest cost per unit of yield. The treatments based on single biological preparations generated higher unit costs, particularly in 2023. The unit costs of maize production in the control treatment (G) remained relatively high, indicating that the absence of biostimulation does not imply lower costs per unit of production; on the contrary, the lower yield increases

the unit production cost. Another indicator expressed the total production value per EUR 1 of direct costs. Once again, the highest values were achieved in treatment E (1.9–2.5 EUR), with very similar results observed for treatment F and, in 2024, also for treatment D. The treatments involving single biological preparations as well as the control treatment produced lower values, indicating less efficient utilization of the incurred inputs (Table 6).

Gross margin per 1 dt of the main product indicates the amount of funds remaining after covering direct costs, expressed per unit of the main product. Once again, the highest gross margin was achieved in treatment E (4.4–7.1 EUR dt^{-1}), while in 2024 a comparable level was achieved in treatment D. It is noteworthy that in the years characterized by favorable market and production conditions (i.e., high yields), the differences between treatments became more pronounced, as observed in 2024. The control treatment and the treatment with Microspeed Energy applied alone produced lower gross margins (Table 10).

Table 9. Unit cost (EUR dt^{-1}) and total production value per EUR 1 of direct costs (EUR) of maize production in 2023–2025

Cultivation treatment*	Unit cost (EUR dt^{-1})			Total production value per EUR 1 of direct costs (EUR)		
	2023	2024	2025	2023	2024	2025
A	6.8	6.8	6.5	1.7	2.2	2.1
B	7.4	7.0	6.5	1.6	2.2	2.1
C	6.7	7.0	6.4	1.7	2.2	2.1
D	7.2	6.1	6.9	1.6	2.6	2.0
E	6.1	6.0	6.1	1.9	2.5	2.2
F	6.7	6.1	6.4	1.7	2.5	2.1
G	7.2	6.9	6.7	1.6	2.3	2.0

Notes: * Symbols are as in Table 1.

Table 10. Gross margin per 1 dt of the main product (EUR dt^{-1}) and profitability index (%) of maize production in 2023–2025

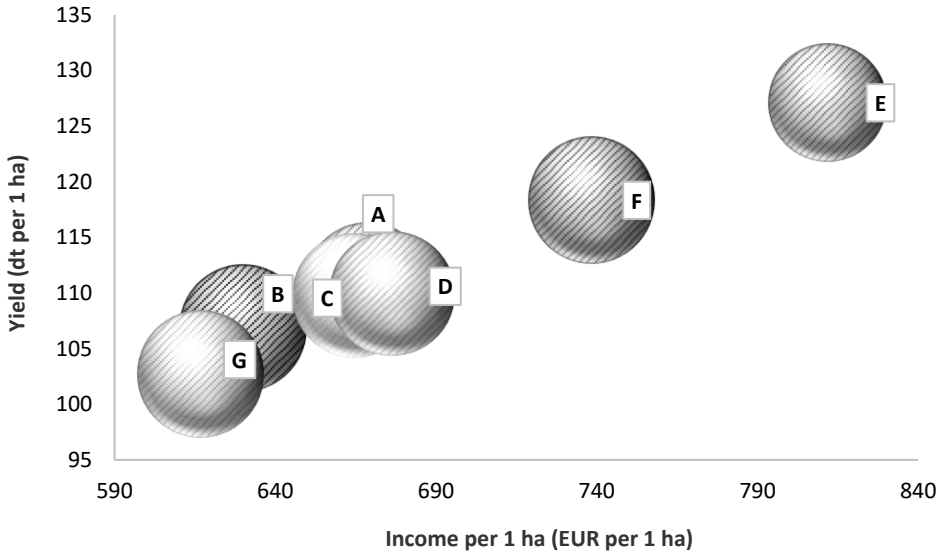
Cultivation treatment*	Gross margin per 1 dt of the main product (EUR dt^{-1})			Profitability index (production value/total costs) (%)		
	2023	2024	2025	2023	2024	2025
A	3.9	6.5	5.3	137.0	171.5	159.0
B	3.4	6.4	5.4	125.0	167.0	159.9
C	4.0	6.4	5.5	137.1	167.2	163.0
D	3.6	7.1	5.1	128.1	193.8	150.9
E	4.4	7.1	5.6	151.3	195.7	169.8
F	4.0	7.0	5.4	138.1	191.7	162.2
G	3.6	6.6	5.3	127.8	170.4	154.5

Notes: *Symbols are as in Table 1.

A profitability index exceeding 100% indicates that production value surpasses total costs. Its highest values were recorded for treatment E (151–196%), indicating that the production value was nearly twofold higher than total costs (particularly in 2024). High profitability indices were also recorded in treatments D and F in 2024, demonstrating that the biostimulation can enhance the benefits

of favorable market conditions. The control treatment and treatment B ensured the lowest profitability, although they remained above the break-even threshold (Table 10). The economic efficiency indicators indicated that treatment E was the most profitable option. In each year of the study, it produced the highest profitability index and the lowest unit cost of maize production. The remaining treatments were characterized by variable profitability levels. It cannot be unequivocally stated which treatment was the least profitable overall. In 2023 and 2024, the lowest profitability index was recorded for treatment B (125% and 167%, respectively), whereas in 2025 – for treatment G (154.5%).

Figure 2. Mean production and economic performance of the analyzed technological treatments applied in maize cultivation in 2023–2025



Notes: The size of the balls represents the production cost of 1 dt of maize grain.

Figure 2 presents the average production and economic results over the three-year study, illustrating the effect of the biological preparations on maize yield and maize cultivation profitability. The figure highlights the pronounced difference between treatments E and F compared with the other treatments. The data presented in Figure 2 confirms the effectiveness of the analyzed preparations and supports the rationale for their combined application at full doses.

DISCUSSION

The FAO report "FAO's Work on Agricultural Innovation" [FAO 2026] emphasizes that innovations are no longer confined to laboratories but have become practical tools for adapting agriculture to climatic, environmental, and economic challenges. Their effectiveness, however, depends on integrating technological advances with farmer knowledge, advisory systems, and cooperation along the food chain. In this context, new agricultural production technologies that incorporate environmentally friendly solutions, including the use of bio-preparations, should also be considered [Calia et al. 2025]. These solutions are part of a broader strategy transitioning from high-input intensification to knowledge-based, resource-efficient, and environmentally sustainable intensification, in line with the European Green Deal and the "Farm to Fork" strategy, or even with the broader framework of the Sustainable Development Goals (SDGs) [European Commission 2020, Kanatas et al. 2022, Quille et al.

2026]. They offer the possibility of partial replacement of agricultural practices used for decades that have proven harmful not only to human health but also to the environment [Mannino 2023, Benďáková et al. 2024].

The study presented here aligns with this line of research by addressing the important issue of the impact of biological agents on the production and economic performance of maize cultivation. It also attempts to assess their practical applicability under farm conditions and their significance for the economic efficiency of production. Biostimulants and other biological products are increasingly recognized as potential tools to support maize cultivation in Europe. These substances, which comprise natural or synthetic products, microorganisms, and various compounds, are applied to plants, soil, or seeds to improve growth, development, yield, and crop quality [Garcia-Sanchez et al. 2024]. However, Ocwa et al. [2024] and Efthimiadou et al. [2020] have emphasized that the mechanisms by which biostimulants enhance crop productivity are not yet fully defined. Therefore, optimizing their application requires understanding both their individual and combined effects. Field effectiveness variability is due to interactions between biostimulants, soil properties, soil microflora, and climatic conditions. Furthermore, bostimulants can be applied alone or in combination with other production means, and at different concentrations [Długosz et al. 2020], potentially eliciting diverse crop responses, as conirmed by the findings of the present study. The observed synergistic effect can be explained by the complementary action of the bio-preparations on the soil microbiome and plant physiology. Microorganisms increase nutrient availability, whereas biostimulants enhance their uptake and mitigate plant stress. Such a mechanism (synergy – nutrient cycling – yield) enables more comprehensive interpretation of the obtained results [Ocwa et al. 2024]. However, it still requires further in-depth investigation.

Study results indicate that the use of biological agents can significantly boost maize grain yields. The greatest effects were observed upon the use of two preparations with complementary modes of action, i.e., the soil-applied microbiological agent that enhances nitrogen and phosphorus uptake, and the metabolic preparation that mitigates plant stress and promotes growth. Similar observations were reported in the literature. For example, a study conducted in the High Valleys of Mexico showed that biostimulants increased maize grain yield by 7.9–11.4% compared with the control treatment [Martínez-Gutiérrez 2022]. In turn, research by Horoszkiewicz et al. [2023] demonstrated that microbiologically-derived biostimulants, such as *Paenibacillus* bacteria, positively influenced maize seed germination and root biomass under optimal conditions in Poland. Other studies have shown that biostimulants helped maize plants withstand abiotic stresses such as drought, salinity, and extreme temperatures [Toscano et al. 2018, Horoszkiewicz et al. 2023]. Trevisan et al. [2018] and Toscano et al. [2018] demonstrated that biostimulants improved nutrient uptake and the efficiency of their further use in maize cultivation, which is crucial for sustainable agriculture. Subsequently, Sobiech et al. [2025] reported that appropriately selected biostimulants positively affected plant growth, physiological parameters, and maize grain yield; however, their effect on grain yield depended on conditions during the growing season. It should be emphasized, however, that a large proportion of the cited studies were conducted under controlled conditions or conditions specific to particular regions, which limits the direct transferability of their results to other cultivation environments. Moreover, the effects of biostimulants are not always consistent and may vary considerably between growing seasons. In turn, Piati et al. [2023] evaluated the influence of biostimulants on gas exchange in maize sown within and outside the recommended period, showing that they can mitigate the negative impact of climate variability. In contrast, few studies have addressed the economic aspects of maize cultivation with biological preparations. This research partially fills this gap. For example, Niewęgłowski et al. [2020] analyzed maize grain profitability under different biostimulants and nitrogen fertilization levels, concluding that using biostimulants with nitrogen doses above 120 kg N ha^{-1}

was economically unjustified. Therefore, achieving stable yields under unpredictable seed market prices should encourage farmers to carefully analyze direct production costs and explore potential reductions. Sible et al. [2021] noted that the effectiveness of biostimulants can vary substantially depending on the preparation applied, environmental conditions, and application method, highlighting the need for careful selection and testing in specific cultivation contexts. In the context of study results, this means that the observed synergistic effect should not be considered universal but rather as dependent on the specific configuration of agrotechnical and environmental factors. The three-year analysis of income per hectare of maize presented in this study shows that the type of preparations and method of their combination have significant economic implications. The highest profitability was achieved in treatment E (Novobakt Azofosfo + Microspeed Energy, 100%). Combining a microbiological agent that enhances phosphorus availability and nutrient use efficiency with a metabolic biostimulant that stimulates physiological processes and stress tolerance produced a clear synergistic effect, exceeding the impact of individual preparations. Treatment F (both preparations at 75% of the full dose) also showed high profitability, indicating that dose reduction does not eliminate the synergistic effect while potentially improving cost–benefit ratio. This represents an attractive option for rationalizing input use. The single-preparation treatments yielded only moderate income increases compared with the control. From an economic perspective, the obtained results indicate high cost–effect trade-offs. Higher doses and combinations of the preparations increase yield potential but also raise direct costs. Although, in the present study, these treatments proved to be the most advantageous, the findings of Szparaga et al. [2019] suggest that higher doses of bio-preparations do not always translate proportionally into higher incomes. In addition, market risk and uncertainty regarding the repeatability of effects in subsequent years should be taken into account, as they may limit farmers' willingness to adopt more costly technologies. Farmers' production decisions will depend on their risk tolerance, capital availability, and market price variability. Cultivation treatments with reduced doses may represent a more economically stable solution and facilitate broader adoption of these technologies. From a practical standpoint, the results suggest that biostimulant implementation should be preceded by an analysis of local conditions and an economic assessment that considers both input levels and yield variability. Particularly promising seem to be the strategies involving combinations of preparations at reduced doses, which allow reducing costs without compromising the production effect. At the same time, decisions regarding their use should be made on an individual basis, taking into account farm-specific conditions.

It should also be emphasized that the study did not include treatments with reduced mineral fertilization; therefore, the results refer to improved nutrient use efficiency rather than the potential for reducing fertilizer application. Consequently, the conclusions regarding sustainable development are indirect and require further verification. An additional limitation is the lack of measurements of biological parameters (e.g., root colonization, microbiological activity, or changes in the microbiome), which means that the interpretation of mechanisms is based primarily on production outcomes and literature data.

CONCLUSIONS

The conducted experiment demonstrated that the application of biological preparations in maize cultivation can significantly improve the economic performance of production; however, this effect is not universal and depends on both the type of preparation and the application strategy. From an economic perspective, the most efficient technologies are those combining agents with different mechanisms of action (microbiological and metabolic), whereas the use of single prepara-

tions results in more variable and limited effects. Such an approach is consistent with the concept of sustainable agriculture, which aims at improving nutrient use efficiency. The application of full-dose combinations is justified under conditions focused on maximizing economic returns, while reduced-dose treatments may represent a compromise solution that improves the cost-effect ratio. It should be emphasized that the observed effects resulted from improved efficiency in the use of production inputs rather than from a reduction or increase in mineral fertilization.

The obtained results indicate that biological agents can serve as an important component of strategies aimed at increasing production efficiency and stabilizing yields, which is relevant both at the farm level and in the context of agricultural policy. Taking into account the environmental objectives of the Common Agricultural Policy, their role should be viewed primarily in terms of improved nutrient use efficiency and the indirect reduction of environmental pressure. However, broader implementation of these technologies requires further research across diverse soil and climatic conditions and over a longer time horizon. This approach would enable assessing the stability of effects. particularly in the case of microbiological preparations, and provide a basis for their effective implementation in agricultural practice and support systems.

Based on the present study's findings and the literature review, it can be concluded that biostimulants offer promising opportunities to improve maize cultivation. When interpreting these results, certain limitations should be considered, which affect the extent of their generalization. The experiment was conducted within a limited range of soil and climatic conditions, meaning that maize responses to the applied preparations might differ in other soil types. The three-year study period allowed assessment of year-to-year variability, but it remains a relatively short horizon for fully evaluating the lasting effects of biostimulation, particularly for the microbiological preparations whose impact may accumulate over time. Future research should expand the spatial and temporal scope of experiments to evaluate maize responses under diverse environmental conditions and to identify long-term effects, particularly in the context of microbiological agents. Future research should integrate the assessment of agronomic efficiency with analyses of biological processes and the testing of reduced-fertilization scenarios, in order to provide a more comprehensive evaluation of the potential of biological agents in achieving the objectives of sustainable agriculture and agricultural policy.

REFERENCES

Amaya-Pérez D.B., Martínez-Damián M.A., Sangerman-Jarquín D.M., 2022. Analysis of technological packages for corn production in the state of Mexico. Rev. Mex. Cienc. Agríc. 16, e3583. https://doi.org/10.29312/remexca.v16i4.3583

Benďáková V., Nagy H., Turčeková N., Adamičková I., Bielik P., 2024. Assessing the climate change impacts on maize production in the Slovak Republic and their relevance to sustainability: A case study. Sustainability 16, 5573. https://doi.org/10.3390/su16135573

Calia C., González García S., Ingra, C., Lagioia G., Ruta C., Secchi N., De Mastro G., 2025. Life cycle assessment of microbial plant biostimulant production for application in sustainable agricultural systems. Sci. Total Environ. 981, 179610. https://doi.org/10.1016/j.scitotenv.2025.179610

Csorba A.B., 2024. Maize production in Central and Eastern Europe – Perspectives and challenges. Acta Univ. Sapientiae Agric. Environ. 16, 117. https://doi.org/10.47745/ausae-2024-0009

Datsko O., Zakharchenko E., Butenko Y., Rozhko V., Karpenko O., Kravchenko N., Sakhoshko M., Davydenko G., Hnitetskyi M., Khrystenko A., 2024. Environmental aspects of sustainable corn production and its impact on grain quality. Ecol. Eng. Environ. Technol. 25, 163. https://doi.org/10.12912/27197050/192537

Długosz J., Piotrowska-Długosz A., Kotwica K., Przybyszewska E., 2020. Application of multi-component conditioner with clinoptilolite and *Ascophyllum nodosum* extract for improving soil properties and *Zea mays* L. growth and yield. Agronomy 10, 1. https://doi.org/10.3390/agronomy10122005

Du Jardin P., 2015. Plant biostimulants: Definition, concept, main categories and regulation. Sci. Hortic. 196, 3–14. https://doi.org/10.1016/j.scienta.2015.09.021

Efthimiadou A., Katsenios N., Chanioti S., Giannoglu M., Djordjevic N., Katsaros G., 2020. Effect of foliar and soil application of plant growth promoting bacteria on growth, physiology, yield and seed quality of maize under Mediterranean conditions. Sci. Rep. 10, 21060. https://doi.org/10.1038/s41598-020-78034-6

Erenstein O., Jaleta M., Sonder K., Mottaleb K., Prasanna B.M., 2022. Global maize production, consumption and trade: Trends and R&D implications. Food Secur. 14, 1295. https://doi.org/10.1007/s12571-022-01288-7

European Commission, 2020. A Farm to Fork Strategy for a fair, healthy and environmentally-friendly food system. European Commission, Brussels.

FAO, 2026. FAO's work on agricultural innovation. https://openknowledge.fao.org/server/api/core/bitstreams/0225024c-ff5e-42a1-b25d-72a67b8e06be/content [accessed on 30 January 2026].

FAOSTAT, 2026. FAOSTAT statistical database. https://www.fao.org/faostat/en/#data [accessed on 30 January 2026].

Gaffney J., Bing J., Byrne P.F., Cassman K.G., Ciampitti I., Delmer D., Habben J., Lafitte H.R., Lidstrom U.E., Porter D.O., Sawyer J.E., Schussler J., Setter T., Sharp R.E., Vyn T.J., Warner D., 2019. Science-based intensive agriculture: Sustainability, food security, and the role of technology. Glob. Food Secur. 23, 236. https://doi.org/10.1016/j.gfs.2019.08.003

Garcia-Sanchez F., Camara-Zapata, J.M., Navarro-Morillo I., 2024. Use of corn steep liquor as a biostimulant in agriculture. Horticulturae 10(4), 315. https://doi.org/10.3390/horticulturae10040315

Grote U., Faße A., Nguyen T., Erenstein O., 2021. Food security and the dynamics of wheat and maize value chains in Africa and Asia. Front. Sustain. Food Syst. 4, 9. https://doi.org/10.3389/fsufs.2020.617009

Horoszkiewicz J., Jajor E., Danielewicz J., Korbas M., Schimmelpfennig L., Mikos-Szymańska M., Klimczyk M., Bocianowski J., 2023. The assessment of an effect of natural origin products on the initial growth and development of maize under drought stress and the occurrence of selected pathogens. Agriculture 13(4), 815. https://doi.org/10.3390/ agriculture13040815

Kanatas P., Travlos I., Gazoulis I., Antonopoulos N., Tataridas A., Mpechliouli N., Petraki D., 2022. Biostimulants and herbicides: A promising approach towards Green Deal implementation. Agronomy 12, 3205. https://doi.org/10.3390/agronomy12123205

Król-Badziak A., Kozyra J., Rozakis S., 2024. Evaluation of climate suitability for maize production in Poland under climate change. Sustainability 16, 6896. https://doi.org/10.3390/su16166896

Maitah M., Malec K., Maitah K., 2021. Influence of precipitation and temperature on maize production in the Czech Republic from 2002 to 2019. Sci. Rep. 11, 10467. https://doi.org/10.1038/s41598-021-89962-2

Mannino G., 2023. A new era of sustainability: Plant biostimulants. Int. J. Mol. Sci. 24, 16329. https://doi.org/10.3390/ijms242216329

Martínez-Gutiérrez A., Zamudio-González B., Tadeo-Robledo M., Espinosa-Calderón A., Cardoso-Galvão J.C., Gricelda M., Vázquez-Carrillo G.M., 2022. Yield of corn hybrids in response to foliar fertilization with biostimulants. Rev. Mex. Cienc. Agríc. 13(2), 289. https://doi.org/10.29312/remexca.v13i2.2782

Miedaner T., Juroszek P., 2021. Global warming and increasing maize cultivation demand comprehensive efforts in disease and insect resistance breeding in north-western Europe. Plant Pathol. 70, 1032. https://doi.org/10.1111/ppa.13365

Niewęgłowski M., Szczygielska M., Kapela K.R., Sikorska A., Krasnodębska E., Zarzecka K.E., Gugała M.J., 2020. An economic evaluation of the use of nitrogen fertilization and growth biostimulants in the production of maize grown for grain. Agron. Sci. 75, 75. https://doi.org/10.24326/as.2020.4.6

Ocwa A., Mohammed S., Mousavi S.M.N., Illés Á., Bojtor C., Ragán P., Rátonyi T., Harsányi E., 2024. Maize grain yield and quality improvement through biostimulant application: A systematic review. J. Soil Sci. Plant Nutr. 24, 1609. https://doi.org/10.1007/s42729-024-01687-z

Panoutsou C., Alexopoulou E., 2020. Costs and profitability of crops for bioeconomy in the EU. Energies 13, 1222.

Piati G.L., Ferreira de Lima S., Lustosa Sobrinho R., Dos Santos O.F., Vendruscolo E.P., Jacinto de Oliveira J., Do Nascimento de Araújo T.A., Mubarak Alwutayd K., Finatto T., Abdelgawad H., 2023. Biostimulants in corn cultivation as a means to alleviate the impacts of irregular water regimes induced by climate change. Plants 12, 2569 https://doi.org/10.3390/plants12132569

Quille P., Kacprzyk J., O'Connell, S.; Ng, C.K.-Y., 2026. Plant biostimulants and their potential role in achieving the United Nations sustainable development goals. New Phytol. (Early View). https://doi.org/10.1002/ppp3.70161

Regulation (EU) 2019/1009 of the European Parliament and of the Council of 5 June 2019 laying down rules on the making available on the market of EU fertilising products. Off. J. Eur. Union L170, 1.

Ruzzante S., Labarta R., Bilton A., 2021. Adoption of agricultural technology in the developing world: A meta-analysis of empirical literature. World Dev. 146, 105599. https://doi.org/10.1016/j.worlddev.2021.105599

Sárvári M., Pepó P., 2014. Effect of production factors on maize yield and yield stability. Cereal Res. Commun. 42(4), 710–720. https://doi.org/10.1556/CRC.2014.0009

Sible C.N., Seebauer J.R., Below F.E., 2021. Plant biostimulants: A categorical review, their implications for row crop production, and relation to soil health indicators. Agronomy 11(7), 1297. https://doi.org/10.3390/agronomy11071297

Skarżyńska A., 2021. Unit costs and income from selected products in 2019 – research results in the AGROKOSZTY system. Probl. Agric. Econ. 367(2), 148–163. https://doi.org/10.30858/zer/138347

Skarżyńska A., Abramczuk Ł., Goławska M., 2022. Wages for paid labor, farmers' own labor payment, and production efficiency in the case of Polish farms classified by types of farming. Probl. Agric. Econ. 370(1), 22–41. https://doi.org/10.30858/zer/145358

Skwarek M., Pipiak, P., 2020. Choroby patogeniczne kukurydzy i rola biostymulatorów w ich zwalczaniu. Technol. Jakość Wyrob. 65, 129-143.

Sobiech Ł., Grzanka M., Idziak R., Blecharczyk A., 2025. The effect of post-emergence application of biostimulants and soil amendments in maize cultivation on the growth and yield of plants. Plants 14, 1274. https://doi.org/10.3390/plants14091274

Szparaga A., Kuboń M., Kocira S., Czerwińska E., Pawłowska A., Hara P., Kobus Z., Kwaśniewski D., 2019. Towards sustainable agriculture – agronomic and economic effects of biostimulant use in common bean cultivation. Sustainability 11(17), 4575. https://doi.org/10.3390/su11174575

Toscano S., Romano D., Massa D., Bulgari R., Franzoni G., Ferrante A., 2018. Biostimulant applications in low input horticultural cultivation systems. Italus Hortus 25(2), 27–36. https://doi.org/10.26353/j.itahort/2018.1.2736

Trevisan S., Manoli A., Ravazzolo L., Franceschi C., Quaggiotti S., 2018. mRNA-sequencing analysis reveals transcriptional changes in root of maize seedlings treated with two increasing concentrations of a new biostimulant. J. Agric. Food Chem. 65, 9956. https://doi.org/10.1021/acs.jafc.7b03069

Wang G., Zhang X., 2024. Maize in global food security: Role and challenges. Field Crop, 7(3), 124-133. https://sophiapublisher.com/cropscipublisher/FC/Vol.7/No.3/4/#zoom=true [accessed on 30 January 2026]

Wang K.L., 2025. Insights into environmental factors affecting maize growth. Maize Genom. Genet. 16(4), 167–181. https://doi.org/10.5376/mgg.2025.16.0016.

Wnuczek R., Nowak A., Haliniarz M., 2026. Production and economic results of spelt wheat cultivation under various conditions of fungicide protection and nitrogen fertilization. Pol. J. Environ. Stud. 35(3), 4359–4370. https://doi.org/10.15244/pjoes/205255

Source of research financing: The publication was financed by a subsidy from the Ministry of Science and Higher Education, from the funds of the Department of Economics and Agribusiness, grant number RKA.SUBB.WRA.19.022.RiO.2026.

Declaration of the use of genAI tools: We declare that this work has not been prepared using generative artificial intelligence (genAI) tools.

Authors' contribution: R.W. – data collection, conceptualization, manuscript review and editing, literature review, methodology supervision, visualisation; A.N. – conceptualization, drafting of the manuscript, literature review, manuscript review and editing, administrative sup-port, visualisation; W.B. – conceptualization, data collection, methodological support, manuscript editing; M.H. – conceptualization, data interpretation, statistical analysis, administrative support, visualisation.

Data availability statement: The raw data supporting results presented in this study are available on request from the corresponding author.

Received: 1.07.2026
Accepted: 3.08.2026
Online first: 24.11.2026

Citation: Wnuczek R., Nowak A., Biszczak W., Haliniarz M., 2026. Economic and production performance of maize under integrated biological agent applications. A three-year field study. Agron. Sci. online first, 1–17. https://doi.org/10.24326/as.2026.5737