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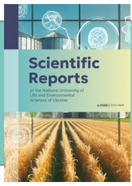

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The effect of preventive treatments with biological preparations on maize productivity

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Abstract. The purpose of the study was to determine the effect of different preventive protection schemes on the phytosanitary condition of the crop, plant growth, yield formation, and grain quality under moisture-deficit conditions. The study used analysis of variance, the method of averages, the method for estimating the mean error, and the method for determining the least significant difference. The results show that chemical protection restricted the development of harmful organisms most strongly: root rot development decreased from 18.6% to 5.1%, leaf spots – from 22.4% to 6.3%, and damage by the European corn borer – from 21.7% to 4.1%. Technical efficacy reached 74.8% against diseases and 81.2% against pests. Biological protection was accompanied by a higher level of preservation of predatory arthropods and actinomycetes, at 54.1%, and by 57.6% when biological preparations were combined with a growth stimulant, compared with 16.3% under the chemical scheme. The combined biological variant showed better biometric parameters: field germination was 90.2%, plant height – 229.4 cm, leaf surface area – 47.6 dm², and chlorophyll content – 47.2 units. In the yield structure of this variant, ear length reached 20.7 cm, average ear mass – 238.0 g, the number of grains per ear – 694, and the 1000-grain mass – 332 g. Grain yield increased from 13.68 to 15.88 t/ha, and yield preservation was 16.1%. Grain quality also improved: test weight increased from 712 to 733 g/l, protein content – from 8.6% to 9.1%, and the proportion of filled grain – from 84.2% to 90.6%, whereas the proportion of damaged grain decreased from 9.8% to 5.0%. The practical value of the study lies in the possibility of using its results by agronomists,

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farmers, plant-protection consultants, and researchers when choosing preventive schemes for maize cultivation under dry conditions

Keywords: growth stimulant; yield; root rots; leaf spots; biological protection

Introduction

The relevance of the study is determined by the increasing effect of drought events on the production process of maize and the need to clarify the crop response to preventive protection systems under water-deficit conditions. When abiotic stress is combined with phytosanitary pressure, the intensity of growth processes, the condition of the leaf apparatus, the formation of generative organs, and grain quality change. In this context, analysis of the effect of biological preparations in preventive schemes becomes important for defining their role both in restraining a complex of harmful organisms and in changing biometric parameters, yield structure, and the level of grain productivity. The combination of biological protection with a growth stimulant is of separate importance, as this scheme requires experimental confirmation under field conditions. The research problem is that the assessment of preventive maize treatments is often presented by separate groups of traits without their sequential analysis within a single production process. This concerns, in particular, the relationship between protection efficacy against diseases and pests, changes in morphological and physiological plant parameters, the formation of yield-structure elements, and the qualitative composition of grain. The comparison of chemical, biological, and combined preventive-protection schemes under a dry background also requires clarification.

With reference to agro-biological characteristics, V. Mazur *et al.* (2023) summarised the conditions for growing maize hybrids in the Right-Bank Forest-Steppe and reported the dependence of productivity on the combination of hybrid properties and technological elements. The researchers stressed the importance of crop adaptability to environmental conditions, which brought that work closer to the assessment of preventive treatments in the field cenosis. In relation to climate variability, P. Boiko *et al.* (2024) analysed the efficiency of maize production in Ukraine when high-yielding hybrids and technologies with elements of biologisation were used. The authors stated that combining the genetic potential of the crop with technological solutions was accompanied by a change in agrocenosis resistance to stress factors. In the technological aspect, A. Drobitko & T. Kachanova (2023) described approaches to developing biologised maize-growing technologies and including biological preparations in the field-protection system. The role of the biological component was presented as part of the general technology, where the phytosanitary effect was combined with changes in growth and yield. At the pre-sowing level, V. Cano Camacho *et al.* (2023) evaluated the effect of biological maize seed treatments on plant growth, soil condition, and yield. It was reported that the use of biological agents was accompanied by changes in crop development and productivity indicators.

C. Sible & F. Below (2023) considered the role of biological preparations in increasing the efficiency of nutrient use by maize and soybean in plant nutrition. Their paper identified a relationship between the biological component of the technology and changes in plant resource provision, which was reflected in growth and grain filling. In the phytosanitary direction, S. Nada *et al.* (2022) examined preventive strategies for mycotoxin control in the wheat and maize chain. Attention was focused on preventive measures associated with reducing contamination and preserving the quality of grain products. In antifungal protection, O. Degani & A. Gordani (2022) evaluated the effect of 6-pentyl-alpha-pyrone against the maize late-wilt pathogen Magnaporthiopsis maydis. Biologically active fungal metabolites were considered a separate tool for restraining pathogens in the maize protection system. Within the microbiome approach, O.P. Omotayo & O.O. Babalola (2023) analysed the potential of a favourable phytomicrobiome in the biocontrol of Fusarium verticillioides in maize crops. The authors stressed the importance of microbial associations as a factor limiting fungal infection and stabilising the phytosanitary condition of plants.

In the field of soil ecology, V. Ninkuu *et al.* (2025) summarised the effect of returning plant residues to the soil on its ecological condition and crop yield. The researchers noted that changes in the soil organic background were combined with shifts in biological activity that were important for plant growth and yield formation. In the nutrition system, P. Hou *et al.* (2025) analysed the optimisation of maize yield under partial replacement of mineral fertilisers with organic ones. The authors reported that fertiliser adjustment changed crop-growth conditions and was accompanied by simultaneous changes in productivity and soil properties. In the context of environmentally safe protection, O.M. Darwesh & I.E. Elshahawy (2023) investigated the use of aqueous vermicompost extract and a biochar derivative to limit sunflower charcoal rot and maize late wilt. The study demonstrated that natural liquid and solid-like substrates were considered components of preventive restraint of vascular and root infections. Within ecological assessment, E. Montemayor *et al.* (2022) carried out a critical analysis of datasets for organic crop-production systems. Attention was focused on the structure of input resources and technological operations, which provided a methodological basis for interpreting biologised crop-growing schemes. The combination of biological preparations with a growth stimulant under drought conditions also remains insufficiently explored, when the response of maize to protective measures is most contrasting. The purpose of the study was to determine the effect of preventive treatments with biological preparations on maize productivity under dry conditions. The objectives of the study were to assess the efficacy of preventive treatments against a complex of harmful organisms, clarify their effect on the growth and development of maize plants, and determine changes in yield-structure elements, yield, and grain-quality indicators.

Materials and Methods

Conditions for establishing and conducting the field experiment

The practical field experiment was established according to a randomised block design with four replications; within each variant, 25 plants were assessed for phytosanitary and biometric determinations, 20 ears were analysed to assess yield structure, 3 average grain samples were collected to determine quality indicators, and 3 soil samples from the arable layer were taken for agrochemical analysis. Field research was conducted in 2025 at the limited liability company AC (agricultural cooperative) PROMIN in the village of Mala Klitna, Khmelnytskyi region, Ukraine. The experiment was established in crops of the maize hybrid DEKALB 4014. The 2025 growing season was characterised by dry conditions; meteorological data were obtained from the Time and Date (n.d.) automatic weather station and field observations. For the study area, the average air temperature in May-September according to climatic norms was 15-20°C, and the total precipitation was 329.1 mm; its uneven distribution created a stressful background for maize growth and the development of a complex of harmful organisms. The soil of the experimental site was typical medium-loamy chernozem. In the 0-30 cm arable layer, humus content was 3.42%, the pH of the salt extract was 6.5, nitrate nitrogen content was 18.6 mg/kg, available phosphorus was 62.4 mg/kg, and exchangeable potassium was 91.7 mg/kg. Winter wheat was the preceding crop. Primary tillage included stubble disking to a depth of 8-10 cm and ploughing to 25-27 cm. Pre-sowing tillage was performed by cultivation at 5-6 cm with simultaneous levelling of the field surface. During the research, the provisions of Convention on Biological Diversity (2016) and the ethical standards of Ethics and data protection (2021) concerning research ethics and data protection were observed.

The fertilisation system was the same for all variants and included the application of $N_{90}P_{60}K_{60}$. Double superphosphate at 130 kg/ha and potassium chloride at 100 kg/ha were applied under primary tillage; ammonium nitrate at 150 kg/ha was applied before pre-sowing cultivation; and carbamide at 100 kg/ha was applied as top dressing at the 6-8 leaf stage. Sowing was conducted in April 2025 using the dotted-row method with 70 cm row spacing and a seeding rate of 75 thousand viable seeds per hectare. Milagro 040 SC herbicide at 1.0 l/ha was applied for weed control at the 4-5 leaf stage of maize. The working-fluid rate was 200 l/ha. The experiment was established according to a randomised block design with four replications. The total plot area was 56 m^2, and the accounting area – 42 m^2. The experimental scheme included four variants: untreated control; chemical protection using the fungicide Amistar Extra 280 SC at 0.75 l/ha and the insecticide Karate Zeon 050 CS at 0.2 l/ha; biological protection using Trykhodermin M at 2.0 l/ha, Planriz M at 2.0 l/ha, Biplan M at 1.5 l/ha, Bitoxibacillin M at 3.0 kg/ha, and Lepidocid M at 2.0 kg/ha; and biological protection combined with the growth stimulant Vympel 2 at 0.5 l/ha against the background of the same biological preparations. Preventive treatments were carried out three times: at the 3-5 leaf stage, at the 7-9 leaf stage, and before tasselling. Spraying was performed with an OPSH (field boom sprayer, Ukraine)-2000-18 boom sprayer in the morning from 6:00 to 9:00 or in the evening from 18:00 to 20:00 at an air temperature not exceeding 25°C and wind speed not exceeding 3-4 m/s. The working-fluid rate for all treatments was 200 l/ha. All other elements of the maize-growing technology were the same for all experimental variants.

Assessment of the efficacy of preventive maize protection under dry conditions

Root rot development was determined by visual assessment of plants using an Eschenbach mobilux 6× hand magnifier (Eschenbach Optik GmbH, Germany) on a 5-point damage scale, where 0 means no symptoms, 1-2 – weak and moderate damage, and 3-5 – severe and very severe damage. Leaf spot development was determined visually on the accounting plants by the proportion of affected leaf surface using a Levenhuk Zeno Handy ZH7 5×/16 mm hand magnifier (Levenhuk Inc., USA) on the same 5-point scale as root rot development. The assessment was conducted by two specialists with higher agronomic education, one of whom held a Candidate of Agricultural Sciences degree. The calculation was performed as the mean percentage of damage for the assessed plants:

$$R = \frac{\sum p_i}{n}, \quad (1)$$

where cap R – average severity of leaf spot disease, %, p_i – proportion of the leaf surface affected in the i-th plant, %, n – number of plants examined, pcs. Stem rot development was determined after dissecting typical stems, followed by assessment of the degree of damage to internal and external tissues. This separately accounted for the spread of destructive processes in the stem complex at the end of the growing season. A Fiskars Solid P321 pruner (Fiskars Group, Finland) was used for dissection. Plant damage by the European corn borer was determined by the proportion of plants with characteristic damage to stems, leaves, and ears. This count assessed the spatial spread of one of the main maize phytophages within the crop. The calculation was performed using the formula:

$$P = \frac{n}{N} \times 100, \quad (2)$$

where P – damage, %, n – number of damaged plants, N – total number of plants surveyed. Aphid infestation was determined by the proportion of plants on which aphid colonies were detected on leaves, sheaths, or stems. This count reflected the degree of spread of sucking insects in the phytocenosis. Technical efficacy against diseases was determined by comparing disease development in the control and treated variants. This value assessed the degree of reduction in infection pressure after application of the preventive schemes. The calculation was performed using the formula:

$$E = \frac{R_k - R_d}{R_k} \times 100, \quad (3)$$

where E – the technical efficiency, %, R_k – the disease progression in the control group, %, R_d – the disease progression in the experimental group, %. Preservation of predatory arthropods and actinomycetes was determined by the ratio between the number of beneficial organisms in the experimental and control variants, and the generalised value for both groups was obtained by integral averaging of normalised indicators. The extent to which the protection system changed the condition of the accompanying biota of the agrocenosis was assessed. Predatory arthropods were counted with a BioQuip Standard Sweep Net (BioQuip Products, USA) in the morning from 7:00 to 9:00, with 10-series sweeps performed on each plot, and the total number of captured individuals was then counted. Actinomycetes were counted by serial dilution of the soil suspension, plating in triplicate on starch-ammonia medium, and cultivation in a Memmert IN55 thermostat (Memmert GmbH, Germany) at 28°C for 7 days. The calculation was performed using the formula:

$$S = \frac{N_d}{N_k} \times 100, \quad (4)$$

where S – survival of beneficial organisms, %, N_d – number of predatory arthropods or actinomycetes in the experimental treatment, N_k – number of predatory arthropods or actinomycetes in the control. Technical efficacy against pests was calculated by the ratio between plant damage or infestation in the control and the experimental variants. The result showed the extent to which the entomological load decreased under the influence of treatments.

Method for determining biometric indicators of maize after treatments

Field germination was determined by counting the number of plants on fixed row segments, followed by recalculation relative to the number of seeds sown. This count established the degree of uniformity in crop formation at the initial stage of development. The calculation was performed using the formula:

$$G = \frac{n}{N} \times 100, \quad (5)$$

where G – the field germination rate, %, n – the number of seedlings emerged, pcs, N – the number of viable seeds sown, pcs. Plant height at the flowering stage, cm, was measured from the soil surface to the top of the tassel using a Stanley 2 m measuring rod (Stanley Black & Decker, USA). This count was used to compare the intensity of stem elongation between the investigated schemes.

Ear placement height was measured from the soil surface to the node of attachment of the upper productive ear using the same measuring rod. This traced the features of the spatial position of the generative organ on the plant. Stem diameter was determined with a Yato YT-7201 calliper (TOYA S.A., Poland) in the middle part of the lower internode. The obtained data were used to assess stem-tissue development and mechanical strength of the plants. The number of leaves per plant was established by direct counting on typical plants with accounting specimens marked using Garden Line plastic field labels (Bradas Group, Poland). This count compared the degree of leaf-apparatus development under different protection schemes. The leaf surface area of one plant was determined from the length and maximum width of leaves using a Topex measuring ruler (Grupa Topex, Poland). The calculated value provided a quantitative expression of the assimilation surface of one plant. The calculation was performed using the formula:

$$S = \sum(L \times B \times k), \quad (6)$$

where cap S is the leaf area of a single plant, cap L is the leaf length (cm), cap B is the maximum leaf width (cm), and k is the leaf shape coefficient. Plant survival until harvest was calculated as the ratio between the number of plants before harvest and the number of plants at the full-emergence stage. This value reflected the final level of crop preservation during the growing season. The calculation was performed using the formula:

$$V = \frac{N_z}{N_s} \times 100, \quad (7)$$

where cap V – plant survival rate prior to harvest, %, cap N_z – number of plants prior to harvest, pcs, cap N_s – number of plants at the full emergence stage, pcs. Chlorophyll content in leaves, SPAD (Soil Plant Analysis Development), was determined with a portable Konica Minolta SPAD-502Plus chlorophyll meter (Konica Minolta, Japan). This count was used to compare the functional condition of leaf tissue between variants.

Approaches to assessing maize yield-structure elements

Average ear length was measured with a Topex ruler after the husks were removed. This count provided an idea of the linear development of the generative organ. Average ear diameter was determined with a Yato YT-7201 calliper in the central part of the ear. The obtained values were used to compare the transverse development of ears. Average ear mass was established using OHAUS Pioneer PA4102C electronic laboratory scales (OHAUS Corporation, USA). This count assessed the overall formation of the ear as a reproductive organ. The number of grain rows per ear was determined by direct counting after the ear was fully cleaned. The number of grains per row was established by manually counting grains in a typical row of the ear. The average number of grains in one ear was calculated as the product of the number of grain rows and the number of grains per row. This calculation provided an integral indicator of the grain capacity of the ear. The formula was as follows:

$$N = a \times b, \quad (8)$$

where cap N is the average number of kernels per cob, pcs., a is the number of rows of kernels per cob, pcs., and b is the number of kernels per row, pcs. The average grain mass from one ear was determined after threshing the ears using OHAUS Pioneer PA4102C laboratory scales. This count was used to assess the actual contribution of one ear to total grain production. The 1,000-grain mass was determined on OHAUS Pioneer PA4102C electronic laboratory scales after counting and weighing a standard sample. The obtained values allowed comparison of the degree of grain filling between the investigated schemes.

Assessment of changes in maize yield under the influence of treatments

Plant density before harvest was determined by counting plants within a 1 m^2 metal frame, followed by recalculation per hectare. This count showed the final number of standing plants per area. The calculation was performed using the formula:

$$D = \frac{n \times 10{,}000}{S}, \quad (9)$$

where D – the plant density prior to harvesting, plants/ha; n – the number of plants in the sample plot, plants; S – the area of the sample plot, m^2. The number of productive ears was determined by counting ears in the same accounting area, followed by recalculation per hectare. This indicator assessed the frequency of generative completion of plants in the crop. The proportion of productive plants was calculated as the ratio between the number of productive ears and the number of plants before harvest. This calculation compared the specific contribution of generatively completed plants within the standing crop using the formula:

$$P = \frac{N_k}{N_r} \times 100, \quad (10)$$

where P – proportion of productive plants, %, N_k – number of productive cobs, pcs, N_r – number of plants prior to harvest, pcs. Grain yield was determined by complete harvesting of each accounting plot with weight accounting of the harvest and subsequent recalculation to standard moisture. The obtained value served as the final quantitative expression of crop productivity. The calculation was performed using the formula:

$$Y = \frac{m \times 10}{S}, \quad (11)$$

where Y – the grain yield, tonnes per hectare; m – the grain weight from the sample plot, kilograms; S – the area of the sample plot, square metres. Yield increase relative to the control was calculated as the difference between the yield of the experimental variant and the control. This value showed the absolute increase in grain production relative to the untreated background and was calculated using the formula:

$$\Delta Y = Y_d - Y_k, \quad (12)$$

where ΔY – the increase in yield compared to the control, t/ha; Y_d – the yield in the experimental treatment, t/ha; Y_k – the yield in the control, t/ha. Yield preservation was determined as the percentage excess of the yield of the experimental variant over the control. This calculation assessed the relative volume of preserved grain production. The formula was as follows:

$$Z = \frac{Y_d - Y_k}{Y_k} \times 100, \quad (13)$$

where Z – harvest retention, %, Y_d – yield in the experimental treatment, t/ha, cap Y_k – yield in the control, t/ha. Grain mass from 1 m^2 was determined by weighing the grain obtained from the accounting area on OHAUS Pioneer PA4102C scales. This count compared the actual output of grain mass from a unit area.

Assessment of the effect of preventive treatments on grain quality

Grain moisture at harvest was determined using a Wile 55 electronic moisture meter (Farmcomp Oy, Finland). This compared the condition of grain at harvest and supported the subsequent recalculation of yield. Grain test weight was determined using a Schopper Type Grain Test Weight Apparatus (Pfeuffer GmbH, Germany). This indicator compared grain bulk density and the level of filling. Protein content was determined by near-infrared spectroscopy using an Inframatic 9500 analyser (Perten Instruments, Sweden). It was used for the quantitative assessment of nitrogenous-compound accumulation in grain. Starch content was determined using the Inframatic 9500 analyser. The obtained values characterised the carbohydrate component of grain production. Crude fat content was established by the extraction method using a Soxhlet VELP SER 148 apparatus (VELP Scientifica, Italy). This assessed the lipid part of the chemical composition of grain. The proportion of filled grain was determined after fractional sorting of the sample, separation of fully formed kernels, and subsequent weighing of fractions on OHAUS Pioneer PA4102C laboratory scales. The indicator was used to establish the proportion of grain with complete filling and formed endosperm. The calculation was performed using the formula:

$$F = \frac{m_1}{m} \times 100, \quad (14)$$

where F – the percentage of filled grains, %, m_1 – the mass of filled grains in the sample, g, m – the total mass of the sample, g. The proportion of shrivelled grain was established during fractional sorting of the sample by separating underdeveloped kernels and subsequently weighing them on OHAUS Pioneer PA4102C laboratory scales. This quantified the proportion of grain with incomplete filling. The proportion of damaged grain was determined after manual sorting of the sample with separation of kernels with mechanical, entomological, and pathological damage, followed by weighing on OHAUS Pioneer PA4102C laboratory scales. Experimental data were processed using analysis of variance based on four replications of the experiment. Mean values were determined for each indicator and served as the basis for comparing the variants under study. Differences between schemes were assessed using one-way analysis of variance, which identified the direction and pattern of changes in the investigated traits. Calculations were performed in Statistica 10.0 (StatSoft Inc., USA) and Microsoft Excel 2019 (Microsoft Corporation, USA).

Results

Under dry conditions, preventive maize treatments changed the course of phytosanitary processes in crops through limitation of disease development, reduction of plant damage by phytophages, changes in the technical efficacy of protection, and different degrees of preservation of the accompanying biota. The lowest level of root rot development was recorded in the chemical-protection variant, where the value was 5.1%. This result reflected the most pronounced limitation of the infection process among the schemes under study. Within this variant, pathogen restraint occurred both at the level of individual plants and within the crop in general, which pointed to a decrease in infection pressure during critical stages of crop development. Under drought conditions, this was accompanied by a lower risk of further plant weakening since moisture deficiency did not remove the harmfulness of infections, but combined with it within a single stress complex. Biological protection also reduced disease development, although the degree of infection suppression was lower. In this variant, pathogen spread was limited within margins that prevented a rapid increase in pathological manifestations in the crop. After the growth stimulant was included in the biological system, the level of damage decreased further, reflecting weaker disease development within the same protection scheme.

A similar pattern was recorded for plant damage by phytophages. In the chemical-protection variant, its level decreased to 4.1%, demonstrating the most pronounced restriction of insect damage among all investigated schemes. This change reflected a sharp decrease in the trophic activity of phytophages during the formation of vegetative mass and generative organs. Under drought conditions, damage to the leaf apparatus and stems was accompanied by direct losses of photosynthetically active surface and disturbance of assimilate distribution between vegetative and reproductive organs. In the biological variant, damage also decreased, but not as sharply as after chemical treatment. This pointed to another type of regulation of phytophage number and activity, under which their presence in the crop was not eliminated completely, but their harmfulness was restrained at a lower level. In the biological protection variant with the growth stimulant, this manifestation weakened further, reflecting a lower degree of damage to the plant cover under the combined action of the preparations.

The level of technical protection efficacy assessed the generalised action of the treatment systems against the complex of harmful organisms. Its highest value was recorded in the chemical scheme, where it reached 81.2%. This reflected the maximum degree of direct control of diseases and phytophages within the experiment. This indicator represented the intensity of protective action but did not cover accompanying changes in the structure of the agrocenosis. In the biological variant, technical efficacy was lower; however, the results show that biological preparations restrained harmful organisms without sharp interference in the accompanying biotic components. After the growth stimulant was included, technical efficacy increased, reflecting greater effectiveness of the biological scheme against the investigated complex of harmful objects. This change was evidence of an expansion of the action range of the system, in which the protective effect was combined with changes in the condition of plants sensitive to water stress. The preservation level of predatory arthropods and actinomycetes in the biological protection variant was 54.1%, reflecting higher preservation of beneficial components of the agrocenosis compared with the chemical scheme. This result demonstrates that the use of biological preparations was characterised by less disturbance of the accompanying biota structure. Under limited moisture, recovery of microbiological and trophic links in the crop occurred more slowly than under a more stable water regime; therefore, preservation of entomophages and actinomycetes was directly related to the condition of internal regulation of the agrocenosis during the growing season. In the chemical variant, this level was substantially lower, which corresponded to a deeper interference in the biological structure of the crop. The combination of biological preparations with the growth stimulant preserved a substantial share of beneficial biota; therefore, within this system, limitation of harmful organisms was combined with less disturbance of accompanying groups (Table 1).

Table 1. *Efficacy of preventive maize treatments against a complex of harmful organisms under dry conditions*

Indicator	Control	Chemical protection (reference fungicide + + insecticide)	Biological protection (Trichodermin M + + Planriz M + Biplan M + Bitoxibacillin M + + Lepidocide M)	Biological protection + growth stimulant (Trichodermin M + + Planriz M + Biplan M + Bitoxibacillin M + + Lepidocide M + Vympel 2)
Root rot development, %	18.6	5.1	6.8	5.9
Leaf spot development, %	22.4	6.3	8.1	7.0
Stem rot development, %	14.8	2.0	3.7	2.9
Plant damage by European corn borer, %	21.7	4.1	6.5	5.4
Aphid infestation of plants, %	19.3	3.8	6.2	5.1
Technical efficacy against diseases, %	0.0	74.8	67.9	71.3
Technical efficacy against pests, %	0.0	81.2	69.8	74.1
Preservation of predatory arthropods and actinomycetes, %	48.0	16.3	54.1	57.6

Source: compiled by the authors

The results show that, under drought conditions, chemical protection ensured the lowest levels of disease development and plant damage by phytophages, along with the highest technical efficacy. Biological protection had a lower degree of direct control but higher preservation of predatory arthropods and actinomycetes. Inclusion of the growth stimulant in the biological scheme was accompanied by a reduction in disease manifestation and plant damage, together with higher technical efficacy, while a substantial share of beneficial biota was preserved. The obtained changes reflected differences between protection systems in the direction of their effect on the phytosanitary condition of the crop and the biological structure of the agrocenosis under insufficient moisture supply. Differences between variants were recorded at the seedling-formation stage. In the biological protection system with the growth stimulant, field germination reached 90.2%. This value was higher than both the control and the separate biological protection without the stimulant. This relationship pointed to a more uniform formation of initial crop density within this variant. For maize under drought, this was methodologically important, as uneven emergence is usually accompanied by stronger intraspecific competition, differences in the growth rates of individual plants, and subsequent stratification of the standing crop by morphological traits. In the control variant, early development was less stable, whereas preventive treatments increased the number of viable plants at the initial stage. Chemical protection was also combined with improvement of this indicator; however, within the biological scheme, after the stimulant was introduced, crop growth from the first vegetation stages was characterised by greater uniformity.

Subsequently, differences between variants remained at the level of above-ground mass formation. In the biological system with the growth stimulant, plant height was 229.4 cm. This value characterised more intensive stem elongation compared with the control and the variant in which only biological preparations were used. Under drought conditions, this difference was related to the specific course of vegetative growth under limited moisture supply. Reduced height under such conditions is usually combined with shorter internodes, earlier growth inhibition, and lower accumulation of above-ground mass. Against this background, taller plants in the treated variants showed less pronounced growth suppression. The chemical scheme was also accompanied by a greater height compared with the control, but in the case of biological protection, after the stimulant was included, this trait was expressed more fully. This distribution between variants was consistent with the differences previously recorded for the phytosanitary condition of the crop. The largest leaf surface area of one plant was recorded in the biological protection variant with the growth stimulant and was 47.6 dm^2. This value characterised a higher level of assimilation-surface development compared with the control and the variant of separate biological protection. Under dry conditions, leaf area had a direct relationship with the functional condition of the crop because a reduction in leaf surface is usually accompanied by a decrease in photosynthetically active tissue and faster transition of plants to a stricter water-saving regime. In the control variant, the leaf apparatus was less developed, which was consistent with the lower level of plant-cover preservation during the growing season. In the chemical and biological variants without the stimulant, this indicator was also higher, but in the combined biological scheme, leaf surface area remained the largest. Within the experiment, this characterised fuller leaf expansion and better preservation of the assimilation apparatus during the dry period.

The functional condition of leaf tissue was also traced through chlorophyll content. The highest value was recorded in the same variant and was 47.2 SPAD. This level characterised higher preservation of the leaf pigment complex compared with the control, where the assimilation apparatus was in a less stable condition. For maize under moisture deficit, this was particularly important for assessing the physiological condition of the crop, because a decrease in chlorophyll is usually associated with weaker synthetic processes, accelerated leaf ageing, and lower intensity of organic matter accumulation. In the chemical variant, this indicator was also higher than in the control, characterising better preservation of functional leaf activity. However, in the biological protection variant with the stimulant, the difference was more pronounced. This supported consideration of the combination of biological preparations and the growth stimulant as a system associated with a higher level of pigment-apparatus preservation under dry conditions. The presented biometric traits did not exist separately from one another but characterised sequential stages of plant development, from emergence to the condition of the leaf apparatus in the main vegetation stages. A higher level of field germination was combined with greater crop uniformity, which was accompanied by higher plant-height values. In turn, more intensive formation of above-ground mass corresponded to a more developed leaf surface and higher chlorophyll content. In the control variant, these traits were expressed more weakly. Under chemical protection, biometric characteristics improved compared with the control. Biological protection without the stimulant was also characterised by a positive shift in most traits, but the highest values for the four considered characteristics were recorded in the variant combining biological preparations with the growth stimulant (Table 2).

Table 2. *Effect of preventive treatments on biometric indicators of maize plants*

Indicator	Control	Chemical protection (reference fungicide + + insecticide)	Biological protection (Trichodermin M + + Planriz M + Biplan M + Bitoxibacillin M + + Lepidocide M)	Biological protection + growth stimulant (Trichodermin M + Planriz M + Biplan M + Bitoxibacillin M + + Lepidocide M + Vympel 2)
Field germination, %	86.9	88.1	88.4	90.2
Plant height at flowering, cm	214.3	223.8	221.6	229.4
Ear placement height, cm	78.6	82.4	81.8	84.9
Stem diameter, mm	19.7	20.9	20.6	21.5
Number of leaves per plant, pcs.	12.4	12.8	12.7	13.1
Leaf surface area of one plant, dm^2	42.8	45.2	44.7	47.6
Chlorophyll content in leaves, SPAD	42.6	45.1	44.8	47.2
Plant survival until harvest, %	82.4	87.1	86.5	89.3

Source: compiled by the authors

Thus, under dry conditions, preventive treatments were associated with changes in maize biometric indicators at different growth stages, from seedling formation to the condition of the leaf apparatus during the growing season. The most uniform initial development, greater plant height, more developed leaf surface, and higher chlorophyll content were recorded in the biological protection variant with the growth stimulant, whereas these traits were weaker in the control and occupied an intermediate position in the other schemes. This relationship reflected differences between variants in individual morphological characteristics and in the degree of plant-cover preservation under insufficient moisture supply. Within the experiment, the recorded changes covered both indicators characterising initial development and crop uniformity and traits associated with above-ground mass formation and the functional condition of the assimilation apparatus. This supported the interpretation of the biometric response of maize not as a set of isolated indicators but as a system of interrelated manifestations that characterised the general condition of plants during growth under drought.

Preventive maize treatments under dry conditions were accompanied by changes in yield-structure elements, which appeared in the relationship between the morphometric characteristics of the ear and traits associated with the formation of the grain part of the yield. In the biological protection variant with the growth stimulant, ear length was 20.7 cm, whereas ears in the control were shorter. This difference characterised a higher level of reproductive-organ development under conditions in which moisture deficiency is usually accompanied by a shorter period of active tissue growth and reduced linear ear parameters. Within the experiment, ear length was not considered a self-sufficient morphometric trait but a characteristic associated with the capacity of the generative structure. Higher values of this indicator in the treated variants corresponded to the formation of ears with fuller development of the axis and better prerequisites for grain-row initiation. In the chemical variant, this trait was also higher than in the control, characterising fuller ear formation under limited moisture supply. Biological protection without the stimulant also increased this indicator, but the most pronounced shift was recorded in the combined biological scheme. This relationship reflected differences between treatment systems already at the level of the spatial organisation of the reproductive organ.

A similar shift was recorded for average ear mass. In the biological protection variant with the growth stimulant, it reached 238.0 g, characterising the fullest formation of generative mass among the investigated schemes. Unlike ear length, this indicator covered morphological size, the degree of tissue filling, the ratio between the cob and grain part, and the general level of dry-matter accumulation within one generative organ. In the control, ears were lighter, which was consistent with weaker yield-structure formation under drought. This distribution of variants reflected unequal levels of realisation of the generative potential of plants. Within the combined biological scheme, greater ear mass was associated with fuller development of its grain part, whereas in the control, the decrease in this trait corresponded to less pronounced mass accumulation in the reproductive organ. Under dry conditions, this was methodologically important, since ear mass is quite sensitive to changes in the water regime and the general condition of plants during flowering and grain filling.

The highest value was recorded in the biological protection variant with the growth stimulant and was 694 grains. This trait characterised the completeness of reproductive-function realisation at the level of an individual plant and reflected the extent to which the formed generative structure retained potential for further filling. For maize under dry conditions, this indicator was sensitive, because water deficit in critical stages is often combined with partial under-pollination, reduction of ovaries, or underdevelopment of some kernels in the upper part of the ear. In the control, the number of grains was lower, which corresponded to less complete realisation of the reproductive capacity of the plant cenosis. In the chemical variant, this indicator increased, and in the scheme with biological protection without the stimulant, it also exceeded the control level, but the maximum value was recorded precisely in the variant with combined application of biological preparations. This relationship characterised greater ear capacity and fuller preservation of the grain row along its entire length. Within yield structure, this trait was of key importance because it combined the morphometric parameters of the ear with the actual level of realisation of its generative load.

The 1,000-grain mass also required consideration as an integral characteristic of individual kernel development. In the biological protection variant with the growth stimulant, it was 332 g, the highest value among the investigated schemes. This trait characterised not the number of formed grains but the degree of their filling, density, and intensity of matter accumulation during the filling period. In the control, this indicator was lower, which corresponded to weaker kernel filling against a background of limited moisture supply. In the chemical variant and in the scheme with biological preparations without the stimulant, the 1,000-grain mass also increased, but its greatest value was characteristic of the combined biological system. This relationship showed that differences between variants were traced both at the level of grain number and within the individual formation of each kernel. In yield structure, this trait completed the chain of morphological and productive characteristics, linking ear parameters with the actual level of grain-mass filling (Table 3). The presented yield-structure elements characterised a sequence of changes that covered ear formation, development of its grain part, and the degree of kernel filling in the final vegetation stages. Increased ear length was accompanied by increased ear mass, and within the same variants, these traits were combined with a larger number of grains and a higher 1000-grain mass. This distribution of indicators reflected a coordinated pattern of yield-structure formation, in which the morphometric parameters of the generative organ were combined with quantitative and weight characteristics of grain production. In the control variant, this complex of traits was weaker, whereas schemes with preventive treatments showed fuller expression of the structural components of yield. This combination was clearest in the biological protection variant with the growth stimulant, where the differences covered not one separate trait but the entire chain of indicators associated with the generative development of maize under dry conditions.

Table 3. *Effect of preventive treatments on maize yield-structure elements*

Indicator	**Control**	**Chemical protection (reference fungicide + + insecticide)**	**Biological protection (Trichodermin M + Planriz M + Biplan M + Bitoxibacillin M + Lepidocide M)**	**Biological protection + growth stimulant (Trichodermin M + Planriz M + Biplan M + + Bitoxibacillin M + Lepidocide M + Vympel 2)**
Average ear length, cm	18.7	20.0	19.6	20.7
Average ear diameter, cm	4.3	4.6	4.5	4.7
Average ear mass, g	196.0	226.0	221.0	238.0
Number of grain rows per ear, pcs.	14.1	15.2	15.0	15.5
Number of grains per row, pcs.	42.0	43.7	43.2	44.8
Average number of grains in one ear, pcs.	592	664	648	694
Average grain mass from one ear, g	182.4	199.8	189.8	209.4
1,000-grain mass, g	308	321	319	332

Source: compiled by the authors

Plant density before harvest required consideration as a characteristic of the actual preservation of the standing crop until the end of vegetation. In the biological protection system with the growth stimulant, it was recorded at 61.1 thousand plants/ha. This crop condition reflected the course of vegetation with fewer plant losses during the season and more uniform preservation of the formed phytocenosis until ripening. In the control, density before harvest remained lower, which was consistent with a greater gap between the formed and actually preserved standing crop. Under chemical protection, crop density also increased, pointing to lower plant losses during critical stages of development. In the scheme with biological preparations without the stimulant, this tendency was also traced, but preservation of the plant composition had not yet reached the degree recorded when biological preparations were combined with the growth-regulating component. This relationship reflected the different effect of preventive treatments on the preservation of the numerical basis of the crop. Within yield formation, this component determined the extent to which the area was provided with plants capable of completing the final development stages without substantial thinning. Therefore, differences between schemes began to appear even before the started the generative stage and created different prerequisites for further formation of productive organs.

The number of productive ears required separate analysis because it reflected the part of the preserved standing crop that completed development with the formation of a full generative organ. In the control, this component was formed at 54.1 thousand ears/ha. This distribution corresponded to lower plant density before harvest and reflected more limited inclusion of plants in the reproductive-development process. Under chemical protection, the number of ears increased, corresponding to fuller transition of plants to the productive state. In the scheme with biological preparations without the stimulant, a shift in the same direction was also recorded, but the relationship between the number of preserved plants and the number of formed ears remained different from that in the combined biological system. When biological protection and the growth stimulant were used together, the number of productive ears was higher, reflecting a different pattern of organogenesis completion within the crop. Thus, differences between schemes concerned preservation of plants as such and the share of plants that passed into the stage of actual productive realisation. In the logic of yield formation, this component connected the morphological basis of the crop with its generative filling, transferring the quantitative characteristic of the standing crop into the plane of productive functioning.

Further generalisation of these changes was focused on grain mass per unit area. When biological protection was combined with the growth stimulant, it was obtained at 1,588 g/m^2. This component reflected the total result of several links in yield formation: plant preservation until harvest, the number of productive ears, the course of grain filling, and dry-matter accumulation in the generative part of the crop. In the control, grain mass per area remained lower, which was consistent with weaker development of the listed components. Under chemical protection, accumulation of grain mass was more intensive, corresponding to changes in crop structure and conditions for forming generative production. In the scheme with biological preparations without the stimulant, grain mass per area also increased, but the filling of a unit area with yield mass occurred within different limits than under the combined action of biological protection and the growth stimulant. This relationship showed that differences between schemes appeared through the number of plants or ears and through the intensity of grain-production accumulation within the agrocenosis. In this regard, grain mass per unit area reflected the transition from structural yield components to the actual volume of formed production accumulated within the accounting area.

The summary of the identified changes was concentrated in grain yield. In the control, it was obtained at 13.68 t/ha. This result was consistent with lower plant density before harvest, a smaller number of productive ears, and lower accumulation of grain mass per area. Under chemical protection, yield increased together with preservation of the standing crop and fuller formation of the generative part of the crop. In the scheme with biological preparations without the stimulant, a positive shift was also recorded, but separate links of yield formation changed within unequal limits; therefore, the general result remained distant from the level obtained under the combined biological action. When biological protection and the growth stimulant were applied together, yield was higher, reflecting the combination of preservation of the plant composition, productive filling of the crop, and greater grain mass per unit area. Thus, yield reflected the cumulative result of changes formed sequentially during vegetation under the influence of preventive treatments. Its level generalised the course of processes associated with plant preservation, transition to generative development, and accumulation of grain production, and therefore reflected the integral response of the maize crop to the applied protection schemes (Table 4).

Table 4. *Effect of preventive treatments on maize yield formation*

Indicator	Control	Chemical protection (reference fungicide + + insecticide)	Biological protection (Trichodermin M + Planriz M + Biplan M + Bitoxibacillin M + Lepidocide M)	Biological protection + growth stimulant (Trichodermin M + Planriz M + Biplan M + + Bitoxibacillin M + Lepidocide M + Vympel 2)
Plant density before harvest, thousand plants/ha	56.8	59.9	59.2	61.1

Table 4. *Continued*

Indicator	Control	Chemical protection (reference fungicide + + insecticide)	Biological protection (Trichodermin M + Planriz M + Biplan M + Bitoxibacillin M + Lepidocide M)	Biological protection + growth stimulant (Trichodermin M + Planriz M + Biplan M + + Bitoxibacillin M + Lepidocide M + Vympel 2)
Number of productive ears, thousand ears/ha	54.1	58.0	57.3	59.5
Proportion of productive plants, %	95.2	96.8	96.8	97.4
Grain mass from 1 m^2, g	1368	1516	1424	1588
Grain yield, t/ha	13.68	15.16	14.24	15.88
Yield increase relative to control, t/ha	0.00	0.74	0.28	1.10
Yield preservation, %	0.0	10.8	4.1	16.1

Source: compiled by the authors

Thus, preventive treatments changed maize yield formation sequentially at several interrelated levels. Their action appeared through plant preservation until the end of vegetation, subsequent formation of productive ears, and grain-mass accumulation within the crop. Without treatment, all these components were formed less completely, whereas the application of protection schemes was accompanied by a shift in yield structure towards better preservation of the plant composition and fuller realisation of generative development. The combination of biological protection with the growth stimulant was characterised by the most coordinated course of these processes, whereas separate use of biological preparations and chemical protection also changed the direction of yield formation compared with the control, but with a different degree of expression of its separate components.

Grain moisture at harvest required primary consideration as a characteristic of the completion of filling and the physiological condition of the kernel at the time of accounting. When biological protection was combined with the growth stimulant, it was recorded at 15.8%. This distribution reflected a different course of ripening, under which the grain entered harvest with a lower moisture content than in the control. Without preventive treatments, this component remained higher, corresponding to a slower transition to technological maturity. Under chemical protection, moisture also decreased, pointing to a different pattern of completion of filling processes. When biological preparations were used without the stimulant, the same trend remained, but the degree of moisture reduction differed from the combined action. Within grain-quality characteristics, this indicator was related to the condition of kernels at harvest and to subsequent storage conditions, the risk of self-heating, and the need for drying. Therefore, differences between the investigated systems reflected features of the final vegetation stages that directly affected the post-harvest properties of the grain mass.

When biological protection and the growth stimulant were used together, grain test weight was obtained at 733 g/l. This value corresponded to the formation of kernels with a denser internal structure and fuller dry-matter accumulation. In the control, test weight remained lower, reflecting another ratio between fully filled and less fully formed kernels. Under chemical protection, this component also shifted towards denser grain mass, which was related to the course of filling and completion of endosperm formation. When biological preparations were used without the stimulant, test weight also increased, but grain bulk density remained within different limits than under the combined effect. From a technological standpoint, this distribution reflected features of the physical composition of grain mass that determine flowability, uniformity, and suitability for storage and processing. In this case, test weight characterised both the mass of grain in a given volume and the degree of completion of processes associated with the deposition of plastic substances during ripening.

When biological protection was combined with the growth stimulant, protein content was determined at 9.1%. This content reflected a different relationship between filling processes and biochemical kernel formation than in the control, where protein concentration remained lower. Under chemical protection, the protein component also increased, which showed a change in the conditions under which nitrogenous substances accumulated in generative organs. When biological preparations were used without the stimulant, this component also deviated from the control in the same direction, but the final protein level differed from that under the combined action. Within the qualitative assessment of grain, this indicator characterised the nutritional completeness of the formed product and reflected the features of metabolic support during filling. Therefore, differences between the investigated systems concerned external kernel properties and its internal composition. In this context, protein was a component linking the agronomic effect of preventive treatments with the biochemical parameters of the formed grain mass.

From the standpoint of product preservation, the proportion of damaged grain required separate analysis. When biological protection and the growth stimulant were used together, it decreased to 5.0%. This distribution reflected a lower spread of kernels with impaired integrity, which was directly linked to the phytosanitary condition of the crop during the generative period. In the control, the proportion of damaged grain was higher, corresponding to a greater presence of morphologically weakened and less uniform production. Under chemical protection, this component also decreased, meaning that preventive action was accompanied by better preservation of the formed grain mass. When biological preparations were used without the stimulant, the proportion of damaged grain also changed in the same direction, but the limits of this decrease differed from those under the combined action. For the market characteristics of the yield, this distribution was important since kernel integrity was linked to preservation during cleaning, transport, storage, and subsequent processing. Within this component, the effect of preventive treatments appeared through a change in the condition of the grain mass as a formed product, rather than only through separate morphological deviations (Table 5).

Table 5. *Effect of preventive treatments on maize grain-quality indicators*

Indicator	Control	Chemical protection (reference fungicide + + insecticide)	Biological protection (Trichodermin M + Planriz M + Biplan M + Bitoxibacillin M + Lepidocide M)	Biological protection + growth stimulant (Trichodermin M + Planriz M + Biplan M + Bitoxibacillin M + Lepidocide M + Vympel 2)
Grain moisture at harvest, %	16.9	16.1	16.4	15.8
Grain test weight, g/l	712	726	721	733
Protein content, %	8.6	8.9	8.8	9.1
Starch content, %	68.2	69.3	69.0	69.8
Crude fat content, %	4.1	4.3	4.2	4.4
Proportion of filled grain, %	84.2	89.1	87.3	90.6

Table 5. *Continued*

Indicator	Control	Chemical protection (reference fungicide + + insecticide)	Biological protection (Trichodermin M + Planriz M + Biplan M + Bitoxibacillin M + Lepidocide M)	Biological protection + growth stimulant (Trichodermin M + Planriz M + Biplan M + Bitoxibacillin M + Lepidocide M + Vympel 2)
Proportion of shrivelled grain, %	10.6	6.2	7.4	5.3
Proportion of damaged grain, %	9.8	5.9	6.8	5.0

Source: compiled by the authors

Thus, preventive treatments changed the quality properties of maize grain in several interrelated directions. Their action appeared through changes in the degree of ripening at harvest, the physical density of the grain mass, the biochemical filling of kernels, and the level of their morphological preservation. Without treatment, these components formed within different limits, whereas the application of protection solutions was accompanied by a shift in grain quality towards lower moisture, a denser structure, higher protein content, and a smaller proportion of damaged kernels. The combination of biological protection with the growth stimulant was characterised by the most integral manifestation of these changes, whereas separate application of chemical protection and biological preparations also affected grain quality compared with the control, but with a different relationship between its separate components. Overall, the quality of the formed product reflected the cumulative result of processes that occurred in the crop from the completion of filling to the condition of the grain mass at harvest.

Discussion

The obtained results show that, under a dry background, different systems of preventive treatments affected the phytosanitary condition of the crop and the morpho-physiological parameters of maize in different ways. Chemical protection ensured the lowest level of disease development and plant damage by phytophages, which reflected the most pronounced limitation of infection and entomological pressure among the investigated schemes. Biological protection was characterised by a higher level of preservation of predatory arthropods and actinomycetes, meaning that it was accompanied by less disturbance of the accompanying biota of the agrocenosis. Inclusion of the growth stimulant in the biological system changed this distribution towards lower plant damage and injury while preserving a substantial share of beneficial organisms. A similar direction was traced in biometric indicators. When biological preparations were combined with the growth stimulant, higher field germination, greater plant height, a more developed leaf surface, and higher chlorophyll content in leaves were recorded. This combination of traits corresponded to a better condition of the assimilation apparatus and more uniform crop development. Against this background, the chemical scheme restricted harmful organisms more strongly, but the combined biological system combined protective action with more favourable plant-growth indicators. Thus, under drought, differences between schemes appeared simultaneously in the phytosanitary, biometric, and physiological planes, reflecting their different effects on the course of the maize production process. From the standpoint of ecological risks of agrochemical protection and physiological regulation of growth, the works of F.H.M. Tang *et al.* (2025) and S. Matthews *et al.* (2025) considered, respectively, the consequences of widespread pesticide use and the potential of biostimulants for increasing crop productivity. F.H.M. Tang *et al.* (2025) summarised pathways of transboundary pesticide transport through water, air, and biotic chains and focused on the ecological and sanitary risks of chemical load. S. Matthews *et al.* (2025) analysed the effect of biostimulants on growth, yield, and product quality and noted their relationship with mitigation of abiotic stress. In this study, the chemical scheme also proved most effective in directly limiting the infection process and plant damage by phytophages, whereas the combination of biological preparations with the growth stimulant was accompanied by higher values of field germination, plant height, leaf surface area, chlorophyll content, and yield.

In the context of integrated regulation of the agrocenosis and natural biostimulating resources, the works of A. Tataridas *et al.* (2022) and S. Matthews *et al.* (2022) focused on early detection of unwanted components of the plant cover, herbicide resistance, integrated management, and safe sources of biostimulating action. A. Tataridas *et al.* (2022) presented an overview of technologies for early diagnosis of invasive species, resistance screening, and approaches to their control, but without detailing changes in biometric and yield indicators of maize. S. Matthews *et al.* (2022) characterised biostimulants as natural and safe resources associated with regulation of growth and metabolic processes. In this study, this line receives experimental continuation: the combined biological scheme reduced disease development and plant damage and was accompanied by higher biometric-trait values and better formation of yield-structure elements. With regard to soil-production changes and phytopathological threat, the works of C.S. Aulakh *et al.* (2022) and Y. Gai & H. Wang (2024) considered, respectively, the consequences of organic farming for soil and yield and the growing global threat of plant diseases. C.S. Aulakh *et al.* (2022) reported that organic systems usually improved soil properties but were often accompanied by lower productivity compared with conventional technologies. Y. Gai & H. Wang (2024) characterised plant diseases as a factor with an increasing effect on food security and yield stability. In the present study, the phytosanitary component is not presented in general terms but through specific field relationships: the minimum development of diseases and damage was recorded under chemical protection, whereas biological protection better preserved beneficial biota, and its combination with the growth stimulant was accompanied by higher indicators of growth, yield structure, and grain quality.

Within the combination of protective and technological measures, the works of N. Nazir *et al.* (2022) and M. Berhe *et al.* (2022) considered different levels of harmful-organism control and product preservation. N. Nazir *et al.* (2022) examined an integrated combination of biological and chemical control and agronomic practices in restraining pea root rots and reported that combined schemes were accompanied by a better phytosanitary condition and higher productivity. M. Berhe *et al.* (2022) summarised the composition of post-harvest insect pests and control practices for food and export crops, focusing on loss of product quality during storage. In this study, a similar relationship between protection and productivity was traced at the field stage: the minimum level of disease damage and plant damage by phytophages was recorded under chemical protection, whereas biological protection with the growth stimulant was accompanied by better biometric indicators, formation of yield-structure elements, and higher yield. In the direction of replacing chemical components with biological and stimulating agents, the works of A.I. Abdo *et al.* (2022) and W.A. Akbar *et al.* (2024) covered approaches to optimising maize yield through changes in the nutrition system and growth regulation. A.I. Abdo *et al.* (2022) analysed the use of growth stimulants in a strategy of partial replacement of chemical fertilisers with biological ones and demonstrated increased maize yield against a background of plant physiological activation. W.A. Akbar *et al.* (2024) reviewed the action of biochar combined with reduced rates of NP (nitrogen-phosphorus) fertilisers and reported changes in soil characteristics, nutrient availability, and maize productivity. In the present study, an analogous direction of change appeared in the variant combining biological preparations with the growth stimulant, where higher values of field germination, plant height, leaf surface area, and chlorophyll content were recorded. Unlike the works of the aforementioned researchers, the physiological effect in this study was traced simultaneously with the level of disease damage, plant damage by phytophages, and preservation of beneficial biota, which broadened interpretation of the action of the combined biological scheme.

In relation to organic improvement of the substrate and biologisation of nutrition R. Suryani *et al.* (2023) and S.F. Lamlom *et al.* (2023) concentrated on changes in yield and product composition under the influence of biochar, trichocompost, biofertilisers, and organic fertilisers. R. Suryani *et al.* (2023) reported that the application of biochar and trichocompost from rice residues was accompanied by increased maize yield and improvement of separate agronomic indicators. S.F. Lamlom *et al.* (2023) demonstrated that biological and organic fertilisers changed the biological and biochemical composition of wheat, in particular, the content of separate grain components. In the present study, a related direction was traced both in yield and in maize grain-quality indicators: variants with preventive treatments were characterised by changes in grain test weight, protein content, starch content, crude fat content, and the proportion of filled grain. In the field of organic fertilisation and microbiological stimulation of germination, the works of M. Cardarelli *et al.* (2022) and V. Antoniadis *et al.* (2023) considered physiological plant responses to non-traditional organic substrates and microorganisms introduced at early stages of ontogenesis. V. Antoniadis *et al.* (2023) reported that insect frass changed soil properties, plant physiological parameters, and nutrient status; therefore, it acted not only as an organic fertiliser but also as a factor regulating growth. M. Cardarelli *et al.* (2022) demonstrated that pre-sowing seed treatments with microorganisms were accompanied by changes in germination energy, germination, and seedling growth, which broadened understanding of the biostimulating role of microbial agents. In this study, the combination of biological preparations with the growth stimulant was also accompanied by higher field germination, greater plant height, greater leaf surface area, and higher chlorophyll content. The advantage of this approach was that early growth responses were considered together with the phytosanitary condition of the crop, the technical efficacy of protection, and subsequent formation of yield-structure elements.

In the field of combining biological agents with the nutrition system, the works of C.A. Phares *et al.* (2022) and T.J. Sande *et al.* (2024) considered variants of integrated plant nutrient supply using biochar, bacteria, vermicompost, and mineral fertilisers. C.A. Phares *et al.* (2022) reported that the joint application of biochar, NPK (nitrogen, phosphorus, and potassium), and plant-growth-promoting bacteria was accompanied by increased maize grain yield and nutrient-use efficiency. T.J. Sande *et al.* (2024) summarised that combining organic and mineral components in nutrition systems changed crop productivity and helped stabilise agronomic indicators. In the present study, a response of similar direction was traced in the variant with biological preparations and the growth stimulant, where plant density before harvest, the number of productive ears, grain mass per area, and yield were higher. A stronger aspect of this work is that productive indicators were considered simultaneously with disease development, plant damage by phytophages, and preservation of beneficial biota. In the field of agronomic regulation of yield traits, the works of F.V. Vijay *et al.* (2022) and N. Sharma & M. Rayamajhi (2022) analysed changes in maize productivity under the influence of zinc nanoparticles and different approaches to weed control. F.V. Vijay *et al.* (2022) demonstrated that the application of zinc oxide nanoparticles was accompanied by changes in yield-structure elements and yield of hybrid maize. N. Sharma & M. Rayamajhi (2022) generalised different aspects of weed control in maize crops and noted that crop condition and final productivity depended substantially on timely restriction of competitive pressure. In the current study, changes were also traced at the level of yield-structure elements; however, they were considered through preventive protection against diseases and pests combined with biostimulating action. A more extensive analytical structure linked increases in ear length, ear mass, grain number, and 1,000-grain mass with the phytosanitary condition of the crop and morpho-physiological plant indicators. The results indicate that preventive maize treatments changed the phytosanitary condition of the crop, morpho-physiological plant indicators, yield-structure elements, yield, and grain quality in different ways, and the most complete integrated effect was recorded when biological preparations were combined with the growth stimulant.

Conclusions

The study compared 4 schemes of preventive maize treatments under dry conditions: untreated control, chemical protection, biological protection, and biological protection combined with a growth stimulant. The analysis covered the phytosanitary condition of the crop, biometric plant indicators, yield-structure elements, yield formation, and grain quality. The results showed that the chemical scheme most clearly restricted the development of the complex of harmful organisms. Root rot development decreased from 18.6% to 5.1%, leaf spots – from 22.4% to 6.3%, stem rots – from 14.8% to 2.0%, and damage by the European corn borer – from 21.7% to 4.1%. Technical efficacy reached 74.8% against diseases and 81.2% against pests. Biological protection and its combination with the growth stimulant better preserved beneficial components of the agrocenosis: the preservation level of predatory arthropods and actinomycetes was 54.1-57.6%, whereas in the chemical variant it was 16.3%. The most extensive changes in biometric indicators were recorded when biological preparations were combined with the growth stimulant. Field germination increased to 90.2%, plant height – to 229.4 cm, ear placement height – to 84.9 cm, leaf surface area – to 47.6 dm^2, and chlorophyll content – to 47.2. In the control, the corresponding values were lower, reflecting weaker development of the plant cover. In the same scheme, yield-structure elements formed more fully: ear length was 20.7 cm, average ear mass – 238.0 g, the number of grains per ear – 694, grain mass from one ear –209.4 g, and the 1,000-grain mass – 332 g. This relationship reflected a better combination of growth processes and generative plant development. Yield formation was also most fully expressed in the biological protection variant with the growth stimulant. Plant density before harvest reached 61.1 thousand plants/ha, the number of productive ears reached 59.5 thousand ears/ha, grain mass from 1 m^2 – 1,588 g, yield – 13.68 t/ha, and yield preservation – 16.1%. For comparison, yield in the control was 6.84 t/ha. Grain quality in this variant was also higher: test weight reached 733 g/l, protein content – 9.1%, starch content – 69.8%, and the proportion of filled grain – 90.6%, whereas the proportions of shrivelled and damaged grain decreased to 5.3% and 5.0%. The limitation of the study was that the field experiment was conducted during one growing season within one farm. Further research should focus on multi-year verification of these schemes in different hybrids and different soil-climatic conditions.

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None.

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Вплив профілактичних обробок біопрепаратами на продуктивність кукурудзи

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Анотація. Метою дослідження було встановити вплив різних профілактичних схем захисту на фітосанітарний стан посіву, ріст рослин, формування врожаю та якість зерна в умовах дефіциту вологи. Було використано метод дисперсійного аналізу, метод середніх величин, метод оцінки похибки середнього, метод визначення найменшої істотної різниці. Встановлено, що хімічний захист найсильніше обмежував розвиток шкідливих організмів: розвиток кореневих гнилей знизився з 18,6 % до 5,1 %, листкових плямистостей – з 22,4 % до 6,3 %, а пошкодженість кукурудзяним метеликом – з 21,7 % до 4,1 %. Технічна ефективність проти хвороб досягла 74,8 %, проти шкідників – 81,2 %. Водночас біологічний захист супроводжувався вищим рівнем збереження хижих видів членистоногих і актиноміцетів – 54,1 %, а при поєднанні біопрепаратів зі стимулятором росту – 57,6 % проти 16,3 % у хімічній схемі. Комбінований біологічний варіант характеризувався кращими біометричними показниками: польова схожість становила 90,2 %, висота рослин – 229,4 см, площа листкової поверхні – 47,6 дм^2, вміст хлорофілу – 47,2 од. У структурі врожаю за цього варіанта довжина качана досягла 20,7 см, середня маса качана – 238,0 г, кількість зерен у качані – 694 шт., маса 1000 зерен – 332 г. Урожайність зерна зросла з 13,68 до 15,88 т/га, а збереження врожаю становило 16,1 %. Якість зерна також покращилася: натура підвищилася з 712 до 733 г/л, вміст білка – з 8,6 % до 9,1 %, частка виповненого зерна – з 84,2 % до 90,6 %, тоді як частка пошкодженого зерна зменшилася з 9,8 % до 5,0 %. Практична цінність дослідження полягає у можливості використання його результатів агрономами, фермерами, консультантами із захисту рослин і науковцями для вибору профілактичних схем вирощування кукурудзи за посушливих умов

Ключові слова: стимулятор росту; врожайність; кореневі гнилі; листкові плямистості; біологічний захист