Research Article

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Yield, volume, quality, and reduction of biotic stress influenced by titanium application in oilseed rape, winter wheat, and maize cultivations

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Abstract: The study presents the results of research on the influence of a mineral growth stimulant containing titanium (Ti) in the form available to plants, applied to reduce the effects of biotic stresses caused by agrophages, namely fungal pathogens and selected insect pests. The study was conducted in 2014 and 2015 on winter oilseed rape, winter wheat, and maize. The purpose of the study was to determine the influence of the Ti-containing stimulant on the degree of damage caused by major pests occurring in the crops (cabbage seed weevil, cereal leaf beetle, and European corn borer), the degree of infestation with fungal diseases (gray mold, *Alternaria* disease, eyespot, foot rot, sooty mold, glume blotch, *Fusarium* head blight, *Fusarium* stalk rot, maize smut,

and brown spot), and yield parameters. The study showed that the stimulant containing Ti successfully reduced the occurrence of pest damage to winter rapeseed and winter wheat plants and the occurrence of diseases in winter rapeseed, winter wheat, and maize crops. Thus, the application of the Ti stimulant resulted in an increased yield of the crops being tested. The main factor explaining this phenomenon is unknown, and it is probably the result of several factors. The study contains the discussion on this phenomenon.

Keywords: plant nutrition, plant disease, pest management systems, maize, oilseed rape, wheat

1 Introduction

In addition to fungicides, herbicides, and insecticides, today's agriculture uses a number of agents classified as plant growth stimulants or biostimulants. Their role involves the regulation and acceleration of life processes, improvement of plant resistance to stress factors, and stimulation of root and leaf development. Due to their mode of action, these substances are safe for the natural environment and thus partially substitute chemical plant-protection agents. The most common groups of substances stimulating plant growth and life processes include phytohormones (e.g., auxins, cytokinins, and gibberellins), bioregulators (e.g., phenols and salicylic acid), biostimulants (also called growth stimulants; phytostimulants), antagonists (fungi and bacteria), and substances, which have an indirect effect on plants through the soil environment and its improvement (soil improvers). Titanium (Ti) belongs to the biostimulant group [1].

Ti is a chemical element of the metal group. It is relatively common in soil, in the form of titanium oxide

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(TiO₂; 0.5–1.5%; on an average of 0.61%). The largest amounts of Ti can be found in volcanic ash [2]. The availability of Ti to plants is strictly connected with the type of soil. It increases along with a decrease in the soil pH and increases in the proportion of organic matter. In Poland, the content of Ti in the soil is less than 1%. The smallest amounts of this element can be found in peaty soils (about 0.05%), whereas the largest amounts are in loamy soils and rendsina soils (about 0.8%) [3]. In spite of the common occurrence of Ti in soil, its ions are not easily accessible to plants. The influence of Ti on plants has been studied for many years. As early as the 1930s, research on Ti content in crops revealed a dependence between this element and silicon (Si). The higher the Si content in plants, the easier it is for them to take up Ti. Similar to Si, Ti exhibits many properties stimulating plants [3–5]. So far, a few mechanisms of stimulating plants have been investigated. However, other aspects have not been investigated, and there are still studies being done to determine the mechanisms of action of Ti ions in plants.

Ti ions intensify the activity of iron ions in plants. This dependence is closely correlated with chlorophyll synthesis, photosynthesis intensity, and the activity of enzymes responsible for the elimination of free radicals, such as peroxidase, catalase, nitrogenase, and nitrate reductase [5]. These effects are particularly important in stressful situations as the plant is much less influenced by the consequences of stress caused by low temperatures, a deficit of light and water, or low activity of the root system. Another important advantage of Ti ions is the fact that they stimulate the uptake of nutrients provided to plants from the soil solution. In consequence, the osmotic pressure in the aerial part of the plant increases. As the plant tries to equalise the pressure, it stimulates the root system to take up more water and nutrients [4]. One of the major advantages of Ti ions is the fact that they increase pollen vitality and positively influence the processes of pollination and fertilization [6]. This advantage is becoming increasingly important in view of the fact that the number of pollinating insects is decreasing dramatically due to chemicals used in agriculture. It has been observed that the application of Ti to plants limits the occurrence of some fungal and bacterial diseases and reduces the level of damage caused by pests [7]. Stimulants containing Ti are known to have direct, positive effects on plants as they increase their size (biomass) and boost plants' natural resistance to biotic stresses such as insect pests and fungal diseases. They improve the quantitative and qualitative parameters of the yield and thus increase the yield [7–9]. Their mechanism of action consists in accelerating the uptake of nutrients, increasing

the activity of iron ions, and increasing the pollen tube receptivity and pollen vitality [10–12]. The aim of this study was to test the possibility of reducing the amount of insect damage and the level of fungal infestation in the aforementioned crops with the use of a mineral growth stimulant containing Ti in the form available to plants. The article presents the results of 2 year experiments on the influence of the liquid biostimulant “Tytanit,” which contains 8.5 g of Ti ions per liter, on winter oilseed rape, winter wheat, and maize.

2 Materials and methods

Tytanit is a liquid biostimulant developed by Intermag Sp. z o. o. (manufactured in Olkusz, Poland). It contains a Ti–ascorbate compound – aqueous complexes of a bioactive form of Ti(IV) for foliar application. Ascorbic acid is among the biorelevant ligands that render Ti(IV) stable in an aqueous solution [13]. The product contains 0.8% (m/m) Ti (8.5 g Ti/L).

The experiments were conducted in winter oilseed rape *Brassica napus* L. (Artoga variety – manufactured by LG Seeds), winter wheat *Triticum aestivum* L. (Figura variety – manufactured by Danco Hodowla Roślin Sp. z o. o.), and maize *Zea mays* L. (Wilga variety – manufactured by HR Smolice Sp. z o. o.) plantations in 2014 and 2015 in Winna Góra, Wielkopolska region (Field Experimental Station of the Institute of Plant Protection – National Research Institute in Poznań), Poland, GPS coordinates (N 52°12'28.8"; E 17°26'16.5"). The station registers all the weather, soil, and other necessary parameters concerning the crops. The aim of the study was to carry out experiments with Si (Zamojska et al. 2018) and Ti in the same conditions. Tytanit containing 8.5 g Ti/L was applied in two different experimental versions (Table 1). The experiments were conducted according to the EPPO PP 1/219 (1), EPPO PP 1/078 (3), EPPO PP 1/017 (3), EPPO PP 1/236 (1), EPPO PP 1/028 (3), EPPO PP 1/013 (3), EPPO PP 1/271 (2), and EPPO PP 1/285 (1) guidelines. The area used for each version of the experiment was 66.4 m² (four replicates, 16.6 m² each). The method of complete randomized block design was applied.

The soil had the following characteristics: soil type: argillaceous sand, soil quality class: IIIa, organic matter: 1.14%, and soil pH: 4.9. Oilseed rape was sown on

Table 1: Versions of the experiment

Name of fertilizer	Fertilizer dose (kg L/ha)
Control	—
Tytanit	0.2
Tytanit	0.4

26 August 2013 and 25 August 2014 (sowing rate: 3.75 kg/ha) and harvested on 28 July 2014 and 30 July 2015. Winter wheat was sown on 27 September 2013 and 23 September 2014 (sowing rate: 190 kg/ha) and harvested on 20 August 2014 and 17 August 2015. Maize was sown on 28 April 2014 and 6 May 2015 (sowing density: 80,000 seeds/ha) and harvested on 29 October 2014 and 30 October 2015.

During the field experiments, the average temperature and the total rainfall (mm) were as follows: March 2014: 6.5°C and 47.0 mm, April 2014: 11.0°C and 40.0 mm, May 2014: 14.1°C and 113.2 mm, June 2014: 18.2°C and 40.0 mm, July 2014: 24.0°C and 64.3 mm, March 2015: 4.9°C and 50.1 mm, April 2015: 8.7°C and 20.1 mm, May 2015: 17.9°C and 31.9 mm, June 2015: 18.1°C and 54.8 mm, and July 2015: 21.6°C and 99.5 mm.

The trials were carried out with standard fertilization:

- Oilseed rape: Polifoska 450 kg/ha (N-18, P₂O₅-54, K₂O-144, MgO-9, SO₃-40.5), ammonium nitrate N 34% (235 kg/ha) – twice.
- Winter wheat: Amofoska 400 kg/ha (N-16, P₂O₅-64, K₂O-72, S-40, CaO-20), ammonium nitrate 34% 235 kg/ha (N-80), and ammonium nitrate 34% 176 kg/ha (N-60).
- Maize: Amofoska 450 kg/ha (N-18, P₂O₅-72, K₂O-81, S-45), Superfosfat 250 kg/ha (P₂O₅-20, S-19), and urea 46% 200 kg/ha (N-96).

The crops were fully protected with pesticides.

The following fungicides containing active ingredients from the group of triazoles, strobilurins, and ketoamines were applied in the experiments:

- Horizon 250 EW (tebuconazole 250 g/L at a dose of 1 L/ha) in winter oilseed rape plantations (treatment in phase BBCH 21),
- Soligor 425 EC (tebuconazole 148 g/L; spiroxamine 224 g/L; and prothioconazole 53 g/L) at a dose of 1 L/ha in winter wheat plantations (treatment in phase BBCH 31),
- Retengo Plus 183 SE (pyraclostrobin 133 g/L; epoxiconazole 50 g/L) at a dose of 1 L/ha in maize plantations (treatment in phase BBCH 39).

The following insecticides containing active ingredients from the group of pyrethroids and neonicotinoids were applied in the experiments:

- Karate Zeon 050 CS (lambda-cyhalothrin 50 g/L) at a dose of 0.12 L/ha in winter oilseed rape plantations (treatments in phases BBCH 16, BBCH 46),
- Avaunt 150 EC (indoxacarb 150 g/L) at a dose of 0.17 L/ha in winter oilseed rape plantations (treatment in phase BBCH 53),
- Proteus 110 OD (thiacloprid 100 g/L + deltamethrin 10 g/L) at a dose of 0.6 L/ha in winter oilseed rape plantations (treatment in phase BBCH 64),

- Minuet 100 EW (zeta-cypermethrin 100 g/L) at a dose of 0.1 L/ha in winter wheat plantations (treatment in phase BBCH 73), and

There were no insecticidal treatments in maize plantations.

The plants were treated with a field backpack sprayer, with a 50 cm boom (sprayer volume 6.0 L, nozzle ID: 4 TeeJet XR11002VSnozzles), at a wind speed of less than 2 km/h. The first treatment was conducted at early stages of the plants' phenological development, when the leaf tissues and meristem were most sensitive to herbivore infestation and fungal diseases. The plants were treated three times: first in phase BBCH 22 (winter wheat), BBCH 12 (maize), and BBCH 21 (winter oilseed rape); second in phase BBCH 40 (winter wheat), BBCH 18 (maize), and BBCH 50 (winter oilseed rape); and third in phase BBCH 73 (winter wheat), BBCH 39 (maize), and BBCH 73 (winter oilseed rape).

In each version of the experiment, damage caused by major insect pests was assessed: damage to oilseed rape siliques caused by cabbage seed weevils, damage to wheat leaves caused by cereal leaf beetles, and damage to maize plants caused by European corn borers. Moreover, the percentage of infestation with fungal diseases and the yield of the crops were assessed.

The experiments were carried out using the methods described in Zamojska et al. [14].

2.1 Assessment methods

Plants, leaves, and siliques were always selected randomly within each plot.

The siliques were collected from the highest oilseed rape sprouts, considering the fact that the highest sprouts are the ones most heavily attacked by cabbage seed weevils. One rape silique, regardless of its size, was randomly selected from each plant.

Hundred plants of winter wheat were randomly collected from each plot. One stem was then collected from each plant.

2.1.1 Assessment of insect damage

The assessments were carried out using the methods described in Zamojska et al. [14]. This involved the following:

- Winter oilseed rape: cabbage seed weevil (*Ceutorhynchus assimilis* Payk.),

- Winter wheat: cereal leaf beetle (*Oulema melanopus* L.), and
- Maize: European corn borer (*Ostrinia nubilalis* Hubner).

2.1.2 Assessment of fungal infestation

The assessments were carried out using the methods described in Zamojska et al. [14]. This involved the following:

- Winter oilseed rape: gray mold (causal agent: *Botrytis cinerea* Pers) and Alternaria disease (causal agent: *Alternaria* spp.).
- Winter wheat: pathogens causing stem base diseases: eyespot (causal agent: *Oculimacula* spp.) and foot rot (causal agent: *Fusarium* spp.), ear diseases: Fusarium head blight (causal agent: *Fusarium* spp.) and glume blotch (causal agent: *Parastagonospora nodorum* E. Müll), and sooty mold (causal agent: *Alternaria* spp.).
- Maize: maize smut (causal agent *Ustilago maydis* (DC.) Corda); on leaves: brown spots (causal agent *Aureobasidium zeae* (Narita & Y. Hiratsuka) Dingley, formerly: *Kabatiella zeae* Narita & Y. Hiratsuka); on cobs: fungi of the *Fusarium* genus.

2.2 Statistical analysis

The results were analyzed statistically with ARM Revision 2018 software. The assumption of the homogeneity of variance attests that the data have been derived from normal distributions with an equal variance. The normality of the distributions for the studied traits was tested using Shapiro–Wilk’s normality test. The Levene test is used to test the hypothesis that the variances across

groups are equal. The two-way mixed analysis of variance (ANOVA) was carried out to determine the effects of years and fertilizers as well as years–fertilizers interaction on the variability of examined traits, for each trait independently. The mean values and standard deviations of traits were calculated. The Fisher’s least significant differences (LSDs) were calculated for individual traits, and on this basis homogeneous groups were determined.

Ethical approval: The conducted research is not related to either human or animal use.

3 Results

ANOVA results indicated that the main effects of year and year $\times$ fertilizer interaction were significant for all the traits of study ($P < 0.001$). The results of the experiments on winter oilseed rape (Table 2) showed that the growth stimulant containing Ti in the form available to plants reduced the number of winter oilseed rape siliques damaged by cabbage seed weevils ($F_{2,18} = 211,900$; $P < 0.001$). As a consequence of the smaller number of oilseed rape siliques damaged by pests, the plants fertilized with Ti were less infested with fungal diseases: gray mold ($F_{2,18} = 692,500$; $P < 0.001$) and Alternaria disease ($F_{2,18} = 582,000$; $P < 0.001$). The experiments showed that due to lesser damage and better health of the plants treated with Ti, the yield increased by 0.16–0.68 tonnes/ha ($F_{2,18} = 1,001.44$; $P < 0.001$).

Similar observations apply to the experiments on winter wheat (Table 3). The flag ($F_{2,18} = 666,500$; $P < 0.001$) and subflag leaves ($F_{2,18} = 334,800$; $P < 0.001$) of the plants fertilized with Ti were less damaged by cereal leaf beetles (*Oulema melanopus* L.), especially in 2014. The infestation

Table 2: The results of experiments on winter oilseed rape. Mean values $\pm$ standard deviations

Year of experiment	Parameters	Control	Tytanit 0.2 kg L/ha	Tytanit 0.4 kg L/ha
2014	Percentage of siliques damaged by cabbage seed weevils	7.75 ^a $\pm$ 0.02	2.80 ^b $\pm$ 0.03	1.50 ^c $\pm$ 0.02
	Mean percentage of siliques infested with fungi			
	Gray mold	22.18 ^a $\pm$ 0.02	9.70 ^c $\pm$ 0.02	10.11 ^b $\pm$ 0.04
	Alternaria disease	15.52 ^a $\pm$ 0.02	10.10 ^b $\pm$ 0.02	7.53 ^c $\pm$ 0.01
2015	Yield (tonnes/ha)	3.96 ^c $\pm$ 0.02	4.58 ^b $\pm$ 0.03	4.64 ^a $\pm$ 0.02
	Percentage of siliques damaged by cabbage seed weevils	11.71 ^a $\pm$ 0.02	2.86 ^c $\pm$ 0.03	8.72 ^b $\pm$ 0.02
	Mean percentage of siliques infested with fungi			
	Gray mold	24.39 ^a $\pm$ 0.02	11.85 ^b $\pm$ 0.02	9.41 ^c $\pm$ 0.04
	Alternaria disease	17.80 ^a $\pm$ 0.02	9.33 ^b $\pm$ 0.03	7.58 ^c $\pm$ 0.01
	Yield (tonnes/ha)	3.40 ^c $\pm$ 0.04	3.81 ^a $\pm$ 0.02	3.56 ^b $\pm$ 0.03

The same superscript letters in each row denote a lack of significant differences.

Table 3: The results of experiments on winter wheat. Mean values $\pm$ standard deviations

Year of experiment	Parameters		Control	Tytanit 0.2 kg L/ha	Tytanit 0.4 kg L/ha
2014	Percentage of leaves damaged by cereal leaf beetle	Flag leaf	70.00 ^a $\pm$ 0.03	23.00 ^b $\pm$ 0.04	18.00 ^c $\pm$ 0.13
		Subflag leaf	58.00 ^a $\pm$ 0.15	28.00 ^b $\pm$ 0.12	10.00 ^c $\pm$ 0.03
	Percentage of plants infested with fungi	Eyespot	48.00 ^a $\pm$ 0.08	7.00 ^b $\pm$ 0.05	4.00 ^c $\pm$ 0.03
		Foot rot	12.00 ^a $\pm$ 0.03	3.00 ^b $\pm$ 0.03	0.00 ^c $\pm$ 0.00
		Sooty mold	20.00 ^a $\pm$ 0.05	1.00 ^b $\pm$ 0.02	1.00 ^b $\pm$ 0.02
		Glume blotch	10.00 ^a $\pm$ 0.04	1.00 ^b $\pm$ 0.05	1.00 ^b $\pm$ 0.04
		Fusarium head blight	10.00 ^a $\pm$ 0.11	4.00 ^b $\pm$ 0.80	0.00 ^c $\pm$ 0.00
		Yield (tonnes/ha)	6.33 ^c $\pm$ 0.03	6.90 ^b $\pm$ 0.02	7.30 ^a $\pm$ 0.03
2015	Percentage of leaves damaged by cereal leaf beetles	Flag leaf	28.25 ^a $\pm$ 0.02	26.75 ^b $\pm$ 0.04	14.75 ^c $\pm$ 0.02
		Subflag leaf	33.75 ^a $\pm$ 0.03	13.25 ^b $\pm$ 0.03	5.00 ^c $\pm$ 0.12
	Percentage of plants infested with fungi	Eyespot	40.0 ^a $\pm$ 0.04	8.00 ^b $\pm$ 0.03	5.00 ^c $\pm$ 0.01
		Foot rot	11.00 ^a $\pm$ 0.03	0.00 ^c $\pm$ 0.00	5.00 ^b $\pm$ 0.03
		Sooty mold	15.00 ^a $\pm$ 0.03	0.00 ^b $\pm$ 0.00	0.00 ^b $\pm$ 0.00
		Glume blotch	5.00 ^a $\pm$ 0.07	1.00 ^b $\pm$ $\pm$ 0.03	1.00 ^b $\pm$ 0.04
		Fusarium head blight	10.00 ^a $\pm$ 0.08	0.00 ^b $\pm$ 0.00	0.00 ^b $\pm$ 0.00
		Yield (tonnes/ha)	8.13 ^c $\pm$ 0.02	8.35 ^b $\pm$ 0.02	8.49 ^a $\pm$ 0.02

The same superscript letters in each row denote a lack of significant differences.

of the plants with fungal diseases was also significantly reduced for eyespot ($F_{2,18} = 2,024,000$; $P < 0.001$), foot rot ($F_{2,18} = 474,800$; $P < 0.001$), sooty mold ($F_{2,18} = 1,217,000$; $P < 0.001$), glume blotch ($F_{2,18} = 55409.8$; $P < 0.001$), and Fusarium head blight ($F_{2,18} = 2037.4$; $P < 0.001$). The yield of the plants fertilized with Ti was 0.22–0.97 tonnes/ha greater than the yield of the control plants ($F_{2,18} = 1,873$; $P < 0.001$).

The experiments on maize (Table 4) showed that the treatment with the product containing Ti reduced the number of plants infested with fungal diseases: Fusarium stalk rot ($F_{2,18} = 5,994$; $P < 0.001$), maize smut ($F_{2,18} = 4,022$;

$P < 0.001$), and brown spot ($F_{2,18} = 447.76$; $P < 0.001$), and increased the yield ($F_{2,18} = 857.77$; $P < 0.001$) by 0.61–1.26 tonnes/ha. The results obtained in the case of the European corn borer varied greatly over the years of the research ($F_{1,18} = 53,237$; $P < 0.001$). Regarding this fact, it cannot be clearly concluded that fertilization influences the scale of damage caused by European corn borers (*Ostrinia nubilalis* Hubner). This requires further research.

In all cases, there were statistically significant differences ($P < 0.001$) in the occurrence of pests and pathogens between the control version and the versions with Ti. Both in 2014 and 2015, the yields of winter oilseed

Table 4: The results of experiments on maize. Mean values $\pm$ standard deviations

Year of experiment	Parameters		Control	Tytanit 0.2 kg L/ha	Tytanit 0.4 kg L/ha
2014	Percentage of plants damaged by European corn borers		21.00 ^a $\pm$ 0.61	18.00 ^b $\pm$ 0.02	12.00 ^c $\pm$ 0.05
		Percentage of plants infested with fungi			
	Fusarium stalk rot		5.00 ^a $\pm$ 0.11	2.00 ^b $\pm$ 0.10	0.00 ^c $\pm$ 0.00
		Maize smut	5.00 ^a $\pm$ 0.22	2.00 ^b $\pm$ 0.08	1.00 ^c $\pm$ 0.03
		Brown spot	2.00 ^a $\pm$ 0.13	1.00 ^b $\pm$ 0.09	0.00 ^c $\pm$ 0.00
2015	Yield (tonnes/ha)		6.29 ^c $\pm$ 0.04	6.90 ^b $\pm$ 0.09	7.04 ^a $\pm$ 0.02
	Percentage of plants damaged by European corn borers		37.14 ^c $\pm$ 0.06	38.56 ^b $\pm$ 0.03	46.06 ^a $\pm$ 0.05
		Percentage of plants infested with fungi			
	Fusarium stalk rot		4.00 ^a $\pm$ 0.14	0.80 ^b $\pm$ 0.03	0.00 ^c $\pm$ 0.00
		Maize smut	5.00 ^a $\pm$ 0.14	0.00 ^b $\pm$ 0.00	0.00 ^b $\pm$ 0.00
		Brown spot	0.00 ^a $\pm$ 0.00	0.00 ^a $\pm$ 0.00	0.00 ^a $\pm$ 0.00
	Yield (tonnes/ha)		8.57 ^c $\pm$ 0.04	9.83 ^a $\pm$ 0.04	9.31 ^b $\pm$ 0.04

The same superscript letters in each row denote a lack of significant differences.

rape, winter wheat, and maize obtained from the Ti versions were always significantly higher than the yield from the control samples. A higher dose of Ti was more effective for the majority of parameters.

4 Discussion and conclusions

The experiments proved the positive effect of the preparation containing Ti ions, which limited the effects of biotic stresses. The preparation reduced damage caused by pests and the infestation of plants with fungal diseases. The fertilizer reduced damage to winter rapeseed and winter wheat plants caused by their major pests. All the plants were less infested with fungal diseases and their yield increased.

The direct factor explaining this phenomenon is unknown because the available scientific publications do not provide an answer to it. It seems that the plants in which stress was reduced with Ti compounds were more resistant to fungal diseases and harmful insects. The fact that Ti has many positive effects on plants might be an indirect cause of this phenomenon. For a long time, Ti has been known to increase the yield of crops. Its beneficial effect has been described in scientific reports [3–5]. However, researchers have not explained this effect in detail. One of the major properties of the Tytanit preparation is the fact that it increases the uptake of nutrients by the root system, especially iron and potassium [7]. Plants may have proteins that (either specifically or nonspecifically) bind with Ti. Plants treated with Ti might be strengthened because the preparation stimulates physiological processes in them. In consequence, plants are in a better condition. They are less susceptible to diseases and less attractive to pests. This relationship between the extent of damage caused by pests and the degree of infestation with fungal diseases has been described in scientific articles [13–15].

It is also known that any environmental stress (biotic or abiotic) has an influence on metabolic changes in plants. Ti may participate in plants' defensive processes, which may cause changes in tissues and inhibit the growth and development of pests' eggs and larvae [16]. There have been studies providing evidence that the quality of plant tissues has an influence on the survival of insects and that there are interactions between the larval growth rate and population size and the plant tissue structure [17]. Some herbivorous insects have chemoreceptors to sense the tissue quality before they attack. They can identify the thickness of plant tissues and sense the

emission of substances such as ethylene. It is likely that Ti also influences volatile and visual features (which may be important for the selection of the host).

There have been numerous scientific reports describing the positive effects of Ti applied to plants' roots or leaves; for example, the increase in the chlorophyll content and photosynthesis intensity in rape plants, a heavier 1,000 kernel weight of wheat, higher sugar content in sugar beets, the reduced effect of *Curvularia* leaf spot, and the lower incidence of bacterial leaf blight in maize [18]. Bacilieri et al. [5] observed that TiO_2 nanoparticles increased the activity of superoxide dismutase, catalase, and glutathione peroxidase in maize at the four-leaf stage. Lu et al. [19] proved that TiO_2 increased the absorption of water and nutrients by soy plants, which strengthened their antioxidative capacity and accelerated their development. Other examples of the positive effect of Ti are increased biomass production in bell peppers (*Capsicum annuum* L.) [20], increased plant height and a greater number of leaves in snapdragons (*Antirrhinum majus* L.) [21], increased plant growth and quality in zonal geraniums (*Pelargonium hortorum* L.) [21], increased seed yield, 1,000 kernel weight, and seed germination in Timothy grass (*Phleum pratense* L.) [22], and increased yield, better fruit quality, higher vitamin content, and higher macronutrient uptake in tomatoes (*Solanum lycopersicum* L.) [7]. Other authors proved that the foliar application of Ti significantly affected the activity of antioxidative enzymes (superoxide dismutase, catalase, and glutathione peroxidase), the content of malondialdehyde, and protein in maize plants [23]. According to Kovacik et al. [24], the Tytanit fertilizer positively influenced the formation of the aerial and underground phytomass of winter oilseed rape. Ercoli et al. [25] also observed that the application of Ti resulted in a higher yield of maize seeds. There have also been reports on the beneficial effect of Ti, which reduced the incidence of diseases and increased the yield of cowpeas (*Vigna unguiculata* Walp.) [6].

This research proves that the inclusion of treatments with preparations containing Ti ions into the technology of production of the plant species being studied increased the effectiveness of integrated crop protection programs. In view of the increasing problem of pests' resistance to crop protection products, the essential rule of the prevention strategy assumes a reduction in the selection pressure of insecticides and fungicides. The results of the experiment show that it is possible to achieve this goal by limiting the occurrence of pests and diseases by means of stimulants containing absorbable Ti. The research findings should be used in strategies for preventing pests' and pathogens' resistance and as the basis for creating

integrated crop protection programs. The research will be continued in other field crops.

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