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The effect of fertilizers containing free amino acids on the yield of modern and old common wheat cultivars in organic production

Wpływ nawozów zawierających wolne aminokwasy na plonowanie współczesnej oraz dawnych odmian pszenicy zwyczajnej w produkcji ekologicznej

Summary. The purpose of the study was to determine the effect of fertilizers with amino acids on the volume and structure of grain yield of modernly grown and old cultivars of winter common wheat in organic production. The following wheat cultivars were evaluated: RGT Kilimanjaro, Ostka Grodkowicka, Square Head Grodkowicka, Egipcjanka, Nadwiślanka and Blondynka. Fertilizer variants included: facility without foliar fertilization, Fertileader Tonic, Ecovigor AA, Fertileader Tonic + Ecovigor AA, Aminosol, Fertileader Tonic + Aminosol. Of the wheat cultivars evaluated, the highest grain yield was that of the contemporary cultivar RGT Kilimanjaro, which yielded an average of 7.27 t ha^{-1}. Old regional wheat cultivars developed grain yields 36.3% to 50.3% lower. In this group of cultivars, Nadwiślanka was characterized by the highest yield potential, and Blondynka by the lowest. The lower grain yields of the old wheat cultivars were the result of weaker plant tillering, a smaller number of developed grains per ear, and a weight of 1,000 grains compared to wheat grown today. The application of fertilizers with amino acids resulted in grain yield increases ranging from 2.4% to 7.2%. A significant increase in yield was found after the application of Fertileader Tonic together with the fertilizers Ecovigor AA and Aminosol.

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Fertilizers with amino acids differentiated ear density and 1,000 grains weight of wheat. Increase in the value of these features was found with the combined application of Fertileader Tonic and Aminosol, and in the case of ear density also after applying Ecovigor AA fertilizer.

Key words: *Triticum aestivum* ssp. *vulgare*, regional cultivar, fertilizers containing free amino acids, grain yield, yield structure

INTRODUCTION

Old wheat species such as *T. dicoccum*, *T. monococcum*, *T. spelta*, *T. persicum*, *T. sphaerococcum*, as well as old (regional) cultivars of *T. aestivum* are gaining popularity in cereal production, especially in organic systems. These wheat cultivars contain more protein, fiber, minerals and vitamins, but yield at a much lower level than commonly grown modern wheat cultivars. One of the main factors determining the yield and quality of wheat grain is an adequate supply of nitrogen to the plant. The fundamental source of nutrients in organic crop production is natural and organic fertilizers generated on the farm, as well as an appropriate crop rotation involving legume crops. However, there are cases when these treatments do not provide sufficient soil fertility therefore soil conditioners or biostimulants are increasingly being used [Shekari and Javanmardi 2017]. An important group of active substances found in biostimulants are amino acids [Calvo et al. 2014]. Protein hydrolysates found in fertilizers are obtained from animal waste or plant biomass [Ertani et al. 2009, Colla et al. 2014, Ławińska et al. 2019]. Free L-amino acids play a major role in plant growth, while D-amino acids have long been treated as growth inhibitors. However, studies show that plants can take up and metabolize both forms of amino acids [Friedman 1999, Bhaskar et al. 2008]. Amino acids play an important biological role as building blocks of proteins, enzymes, nucleic acids, antioxidants and plant hormones [Shukla et al. 2014, Popko et al. 2018]. By providing amino acids from outside, plants do not lose energy to produce them, and this energy can be used for faster and better plant growth. Due to their structure, they act as buffers that maintain favorable pH in plant cells, positively influence photosynthesis and mitochondrial respiration [Meijer 2003, Khan 2019]. Under adverse environmental conditions, they mitigate the effects of abiotic stresses on plants [Drobek et al. 2019]. In a study by Hammad and Ali [2014], the application of an amino acid preparation mitigated the adverse effects of drought in wheat crops, while Pooryousef and Alizadeh [2014] demonstrated the beneficial effects of amino acids for alfalfa seedlings grown under conditions of excessive soil moisture. Formulations rich in free amino acids can also play an important role in increasing plant tolerance to both low and high temperatures [Kauffman et al. 2007, Botta 2013]. In other studies, fertilizers with amino acids mitigated the harmful effects of soil salinity in field bean and corn crops [Ertani et al. 2013, Sadak et al. 2015]. The effectiveness of amino acid formulations was also demonstrated in protecting plants from disease culprits [Wojdyła 2017, 2018].

The aim of the study was to determine the size and structure of grain yield of common wheat grown today and old regional cultivars of this species in an organic production system under the influence of feeding the plants with fertilizers containing amino acids.

MATERIAL AND METHODS

The research was carried out during the growing seasons: 2018/2019, 2019/2020 and 2020/2021 at the Experimental Station in Prusy (50°07'N and 20°05'E) belonging to the University of Agriculture in Krakow. The field experiment was established on Haplic Chernozem (*Siltic*), included in the very good wheat complex and 1st soil quality class in a randomized block design with 3 replications. Arable layer of soil (0–30 cm) was characterized by: high abundance of phosphorus (73–78 mg P kg^{-1}); medium abundance of potassium (131–142 mg K kg^{-1}); high abundance of magnesium (56-64 mg Mg kg^{-1}); C_{org} content of 11.3 g kg^{-1}; neutral reaction (pH_{KCl} 6.8–7.0); content of sand 120–130 g kg^{-1}; silt 533–540 g kg^{-1} and clay 337–345 g kg^{-1}. The factors of the experiment were cultivars and fertilizers with amino acid. Regional winter wheat cultivars were evaluated: Ostka Grodkowicka (*T. vulgare* var. *ferrugineum*), Square Head Grodkowicka (*T. vulgare* var. *albidum*), Egipcjanka (*T. vulgare* var. *graecum*), Nadwiślanka (*T. vulgare* var. *erythrospermum*) and Blondynka (*T. vulgare* var. *erythrospermum*), and a contemporary cultivated cultivar recommended for organic production RGT Kilimanjaro. Fertilizer variants included: A – facility without foliar fertilization, B – Fertileader Tonic (1.5 dm^3 ha^{-1}), C – Ecovigor AA (3 dm^3 ha^{-1}), D – Ecovigor AA + Fertileader Tonic (3 dm^3 ha^{-1} + 1.5 dm^3 ha^{-1}), E – Aminosol (3 dm^3 ha^{-1}), F – Aminosol + Fertileader Tonic (3 dm^3 ha^{-1} + 1.5 dm^3 ha^{-1}). Fertilizers containing free amino acids were applied at the tillering stage (BBCH 27–29), in cloudy weather or in the evening at an air temperature of about 15°C. In the wheat crop, Physio-Natur PKS 47 was applied before sowing at a rate of 300 kg ha^{-1} and Fertil Bioilsa CN 40–12.5 at a rate of 400 kg ha^{-1} for top dressing, in the spring. The characteristics of foliar fertilizers are shown in Table 1.

Table 1. Characteristics of fertilizers containing free amino acids

Fertilizer	Composition
Fertileader Tonic	Seactiv complex (glycine-betaine, adenine isopentyl, amino acids), Cu 4.8%, Mn 7.7%
Ecovigor AA	Seactiv complex (glycine-betaine, adenine isopentyl, amino acids), N 3%, K_2O 7%, glutamine 11.78%, methionine 1.92%, asparagine 0.21%, alanine 0.17%, proline 0.15%, glycine 0.14%, serine 0.10%, leucine 0.10%, tyrosine 0.10%, lysine 0.09%, isoleucine 0.06%, arginine 0.05%, valine 0.05%, hydroxyproline 0.04%, phenylalanine 0.03%
Aminosol	N 9,4%, K_2O 1.1%, S 0.25%, Na 1.28%, organic matter 66.3%, amino acids and peptides 56–58%

The size of the harvest plot was 10 m^2. The forecrop for wheat was peas. Sowing was done in the 3rd decade of September, and harvesting was in the 1st – 2nd decade of August. The sowing rate was 450 germinating grains per 1 m^2. Seed of regional cultivars was obtained from the Experimental Department of the Institute of Plant Breeding and Acclimatization in Grodkowice. Weed control was carried out mechanically by harrowing in autumn at the 3–4 leaf stage and twice in spring up to the stalk shooting stage.

The study determined grain yield (at 13% moisture content), spike density, number of grains per ear, weight of 1,000 grains and agricultural harvest index HI. The results were subjected to statistical evaluation using an analysis of variance. Highly significant differences (HSD) for the investigated features were verified using Tukey's test at a significance level of $p < 0.05$.

The characteristics of weather conditions are shown in Table 2. All growing seasons in the cycle of the conducted field research were characterized by air temperature higher than the corresponding multi-year period. The highest average air temperature (11.5°C) was recorded in the 2019/2020 season, which was characterized by very high temperatures during the autumn wheat growing season and a short period of winter plant dormancy. Extremely high air temperatures also prevailed in June 2019. Winter wheat growing periods differed significantly in moisture conditions. In the first season of the study (2018/2019), the amount of precipitation was close to the multi-year average but its distribution was very uneven. In May 2019, the amount of precipitation exceeded rainfall needs four times, and in June it was four times less than the needs. In the 2019/2020 season, the driest in the study cycle, significant precipitation shortfalls were recorded during the early spring growing season (March, April). The highest amount of precipitation was noted in the 2020/2021 season, both in the autumn and spring wheat growing season. Throughout the season, the amount of precipitation was 265 mm higher than the multi-year average.

Table 2. Characteristics of weather conditions

Month	Growing season						Mean
	2018/2019		2019/2020		2020/2021		
air temperature (°C)							
September	16.1		14.7		15.8		13.7
October	10.4		17.6		10.4		8.7
November	4.5		9.9		8.7		3.6
December	1.2		6.5		3.3		–0.5
January	–2.1		0.6		-0.9		–1.5
February	3.1		3.7		-0.9		–0.2
March	6.2		5.6		3.6		3.5
April	10.3		10.8		6.4		9.1
May	12.4		11.4		12.6		14.2
June	22.2		17.9		19.5		17.3
July	19.2		19.1		21.3		19.2
August	20.5		20.7		17.5		18.6
Mean	10.3		11.5		9.8		8.8
rainfall (mm)							
month	rainfall	needs*	rainfall	needs	rainfall	needs	
September	70.8	–	88.6	–	105.4	–	65.1
October	52.3	–	35.7	–	104.4	–	47.4
November	11.7	–	41.9	–	23.6	–	42.6
December	51.2	–	39.2	–	17.0	–	33.9
January	44.2	–	14.7	–	31.6	–	36.0
February	12.8	–	42.6	–	40.2	–	31.3
March	21.4	–	14.4	–	19.8	–	38.7
April	76.2	39.5	7.8	41.7	64.0	22.9	48.9
May	205.2	52.6	89.6	48.5	86.8	53.7	76.7
June	22.4	85.9	88.8	67.6	112.4	74.3	82.0
July	53.2	56.3	56.0	55.6	139.2	65.1	96.2
August	88.2	–	37.6	–	191.0	–	71.8
Sum	687.2	234.3	556.9	213.4	935.4	216.0	670.6

* rainfall needs according to Klatt [citation for Nyc 2006]

RESULTS AND DISCUSSION

Grain yields of winter wheat grown according to the principles of organic production were in a wide range from 3.44 to 7.54 t ha^{-1} and depended on the cultivar, the fertilizer variant, the year of the study and the interaction of these factors (Tab. 3, Fig. 1a).

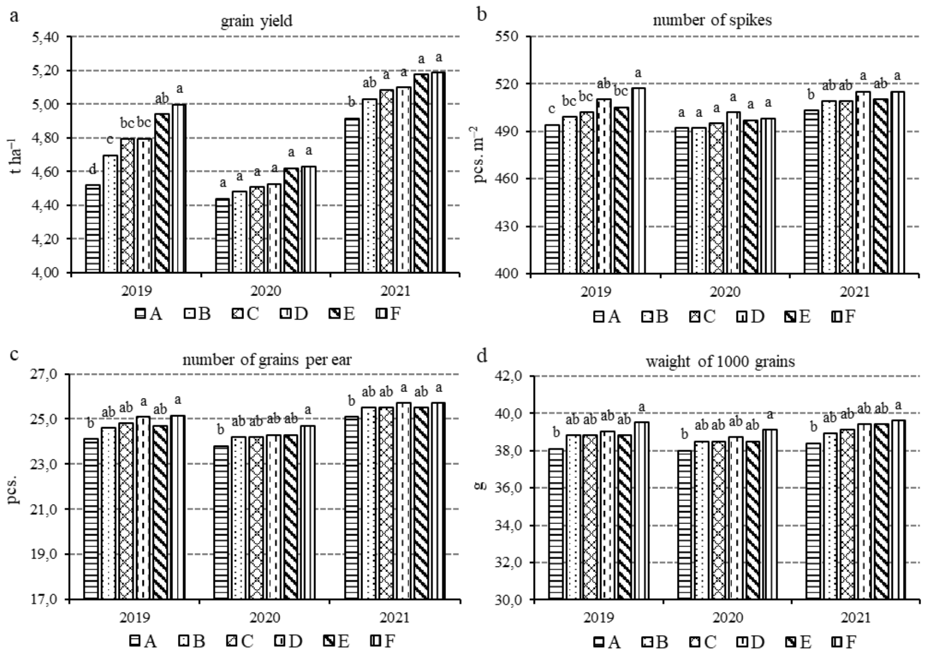

Fig. 1. Grain yield (a), number of spikes (b), number of grains per ear (c) and weight of 1000 grains of winter wheat (d) depending on the fertilization variant and harvest year

The highest grain yield was observed for the contemporary cultivar RGT Kilimanjaro, averaging 7.27 t ha^{-1}, while the old wheat cultivars yielded 36.3 to 50.3% lower. In this group of cultivars, Nadwiślanka had the highest yield (4.63 t ha^{-1}) and Blondynka had the lowest (3.61 t ha^{-1}). In the study of Stalenga and Jończyk [2007], the yields of old wheat cultivars (Wysokolitewka Sztywnosłoma, Kujawianka Więcławicka, Ostka Kazimierska) ranged from 2.03 to 2.58 t ha^{-1} and were lower than those of modern cultivars by 42.3% on average. According to the authors, the higher productivity of modern wheat cultivars was determined by higher ear density and grain ripeness. According to Kołodziejczyk and Szmigiel [2014], as well as Rachoń et al. [2014], the components of wheat grain yield that most strongly determine its size are ear density and the number of grains per ear. In the conducted study, the highest ear density of 566 pcs m^{-2} was found for RGT Kilimanjaro cultivar, while old cultivars developed from 6.5 (Ostka Grodkowicka) to 17.5% (Square Head Grodkowicka) fewer ears per unit area (Tab. 4).

Table 3. Grain yield of winter wheat (t ha^{-1})

Cultivar	Fertilizer variant						Year of harvest			Mean
	A*	B	C	D	E	F	2019	2020	2021	
RGT Kilimanjaro	7.00^{a}**	7.05^{a}	7.29^{a}	7.54^{a}	7.24^{a}	7.48^{a}	7.57^{a}	6.46^{a}	7.73^{a}	7.27^{A}
Ostka Grodkowicka	4.20^{c}	4.50^{bc}	4.51^{b}	4.51^{bc}	4.46^{b}	4.63^{bc}	4.11^{c}	4.35^{bc}	4.95^{b}	4.47^{B}
Square Head Grodkowicka	4.24^{bc}	4.31^{c}	4.40^{b}	4.47^{c}	4.41^{b}	4.56^{bc}	4.30^{bc}	4.26^{bc}	4.64^{bc}	4.40^{B}
Blondynka	3.44^{d}	3.59^{d}	3.55^{c}	3.71^{d}	3.66^{c}	3.73^{d}	3.69^{d}	3.38^{d}	3.78^{d}	3.61^{C}
Egipcjanka	4.25^{bc}	4.34^{bc}	4.39^{b}	4.52^{bc}	4.46^{b}	4.46^{c}	4.51^{b}	4.17^{c}	4.52^{c}	4.40^{B}
Nadwiślanka	4.48^{b}	4.56^{b}	4.62^{b}	4.74^{b}	4.61^{b}	4.78^{b}	4.56^{b}	4.46^{b}	4.88^{b}	4.63^{B}
Mean	4.61^{B}	4.72^{AB}	4.79^{AB}	4.91^{A}	4.81^{AB}	4.94^{A}	4.79^{B}	4.52^{C}	5.08^{A}	–

*A – facility without foliar fertilization, B – Fertileader Tonic, C – Ecovigor AA, D – Ecovigor AA + Fertileader Tonic, E – Aminosol, F – Aminosol + Fertileader Tonic

** Means within columns for each data type followed by the same letter do not differ significantly at $p \leq 0.05$

Table 4. Components of winter wheat field

Cultivar	Fertilizer variant						Year of harvest			Mean
	A*	B	C	D	E	F	2019	2020	2021	
number of spikes (pcs. m^{-2})										
RGT Kilimanjaro	559^{a}**	562^{a}	563^{a}	576^{a}	566^{a}	570^{a}	587^{a}	542^{a}	569^{a}	566^{A}
Ostka Grodkowicka	517^{b}	524^{b}	527^{b}	535^{b}	531^{b}	538^{b}	506^{b}	534^{b}	547^{b}	529^{B}
Square Head Grodkowicka	457^{f}	462^{e}	467^{d}	472^{d}	467^{d}	477^{d}	459^{d}	468^{d}	475^{e}	467^{D}
Blondynka	468^{e}	472^{d}	471^{d}	476^{d}	475^{d}	479^{d}	477^{c}	469^{d}	474^{e}	473^{D}
Egipcjanka	480^{d}	489^{c}	488^{c}	495^{c}	492^{c}	495^{c}	497^{b}	481^{c}	492^{d}	490^{C}
Nadwiślanka	492^{c}	494^{c}	496^{c}	499^{c}	494^{c}	502^{c}	499^{b}	484^{c}	506^{c}	496^{C}
Mean	497^{B}	499^{B}	502^{AB}	509^{A}	504^{AB}	510^{A}	504^{AB}	496B	510^{A}	–
number of grains per ear (pcs.)										
RGT Kilimanjaro	31.2^{a}	31.5^{a}	31.8^{a}	32.1^{a}	31.7^{a}	32.5^{a}	32.2^{a}	30.3^{a}	32.8^{a}	31.8^{A}
Ostka Grodkowicka	22.0^{d}	22.9^{c}	23.1^{c}	22.9^{d}	23.0^{c}	23.0^{c}	22.7^{c}	22.4^{c}	23.3^{c}	22.8^{C}
Square Head Grodkowicka	23.7^{b}	23.9^{b}	24.0^{b}	24.3^{b}	24.2^{b}	24.3^{bc}	23.8^{b}	23.4^{b}	25.0^{b}	24.1^{B}
Blondynka	23.2^{bc}	23.5^{bc}	23.7^{bc}	23.9^{bc}	23.6^{bc}	23.7^{bc}	23.7^{b}	23.3^{bc}	23.8^{bc}	23.6^{BC}
Egipcjanka	23.2^{bc}	23.6^{bc}	23.3^{bc}	23.5^{cd}	23.4^{c}	23.8^{bc}	23.1^{bc}	23.1^{bc}	24.2^{b}	23.4^{BC}
Nadwiślanka	22.7^{cd}	23.3^{bc}	23.2^{c}	23.5^{cd}	23.3^{c}	23.6^{bc}	22.7^{c}	23.2^{bc}	23.8^{bc}	23.3^{BC}
Mean	24.3^{A}	24.7^{A}	24.8^{A}	24.9^{A}	25.0^{A}	25.1^{A}	24.7^{B}	24.3^{B}	25.5^{A}	–
weight of 1000 grains (g)										
RGT Kilimanjaro	40.7^{a}	41.0^{a}	41.5^{a}	41.6^{a}	40.8^{a}	41.3^{a}	40.5^{a}	40.8^{a}	42.2^{a}	41.2^{A}
Ostka Grodkowicka	37.8^{c}	38.3^{c}	38.2^{c}	38.6^{c}	38.7^{d}	39.0^{b}	38.5^{b}	37.2^{d}	39.6^{c}	38.4^{C}
Square Head Grodkowicka	39.7^{b}	40.0^{b}	39.9^{b}	40.2^{b}	39.9b^{c}	40.5^{a}	40.0^{a}	40.2^{b}	39.9^{c}	40.0^{BC}
Blondynka	32.8^{d}	33.5^{d}	33.3^{d}	33.7^{d}	34.0^{e}	34.9^{c}	33.9^{c}	33.4^{e}	33.8^{e}	33.7^{D}
Egipcjanka	38.4^{c}	38.6^{c}	38.8^{c}	39.2^{c}	39.3^{cd}	39.1^{b}	39.7^{a}	38.8^{c}	38.1^{d}	38.9^{C}
Nadwiślanka	40.2^{ab}	40.6^{ab}	41.0^{a}	41.1^{a}	40.7^{ab}	41.4^{a}	40.5^{a}	40.8^{a}	40.8^{a}	40.8^{AB}
Mean	38.2^{B}	38.7^{AB}	38.8^{AB}	38.9^{AB}	39.0^{AB}	39.4^{A}	38.9^{A}	38.5^{A}	39.1^{A}	–

Explanation as in Table 3.

Lower productivity of the old wheat cultivars was also a result of the low number of grains per ear. The average number of grains in an ear of wheat grown today was 31.8, while the number of grains in ears of old cultivars ranged from 22.8 to 24.1. The study also showed a lower weight of 1,000 grains of old winter wheat cultivars than RGT Kilimanjaro wheat. Similar research results were obtained by Stalenga and Jończyk [2007] and Konvalina et al. [2012]. Components of cereal grain yield, such as the number of grains per ear, the weight of 1,000 grains or the weight of grains per ear, are determined by the genetic properties of the cultivar and are characterized by a high coefficient of heritability, so they are subject to environmental variability to a lesser extent than ear density [Zecevic et al. 2010, Knezevic et al. 2014]. Also, the value of the harvest index (HI) is mainly determined by varietal characteristics and less by environmental factors or agrotechnology [Porker et al. 2020, Jaenisch et al. 2022]. The spread of cultivation of short-stemmed wheat cultivars in the 1970s significantly increased the level of yield and the value of the harvest index. In the study conducted, the harvest index (HI) was at a low level and ranged from 0.27-0.28 in the case of old winter wheat cultivars to 0.38 in the contemporary cultivated cultivar RGT Kilimanjaro (Tab. 5).

Table 5. Agricultural yield index (HI) of winter wheat

Cultivar	Fertilizer variant						Year of harvest			Mean
	A*	B	C	D	E	F	2019	2020	2021	
RGT Kilimanjaro	0.36^{a**}	0.37^{a}	0.37^{a}	0.38^{a}	0.38^{a}	0.39^{a}	0.37^{a}	0.35^{a}	0.41^{a}	0.38^{A}
Ostka Grodkowicka	0.27^{b}	0.28^{b}	0.28^{b}	0.29^{b}	0.28^{b}	0.29^{b}	0.27^{b}	0.25^{b}	0.32^{b}	0.28^{B}
Square Head Grodkowicka	0.26^{b}	0.26^{c}	0.27^{b}	0.28^{b}	0.28^{b}	0.28^{b}	0.24^{cd}	0.26^{b}	0.33^{b}	0.27^{B}
Blondynka	0.26^{b}	0.27^{bc}	0.28^{b}	0.28^{b}	0.28^{b}	0.29^{b}	0.23^{d}	0.26^{b}	0.33^{b}	0.28^{B}
Egipcjanka	0.26^{b}	0.28^{b}	0.27^{b}	0.28^{b}	0.27^{b}	0.28^{b}	0.25^{c}	0.25^{b}	0.33^{b}	0.27^{B}
Nadwiślanka	0.27^{b}	0.28^{b}	0.27^{b}	0.29^{b}	0.28^{b}	0.29^{b}	0.24^{cd}	0.26^{b}	0.33^{b}	0.28^{B}
Mean	0.28^{B}	0.29^{AB}	0.29^{AB}	0.29^{AB}	0.30^{A}	0.30^{A}	0.27^{B}	0.27^{B}	0.34^{A}	–

Explanation as in Table 3.

Regardless of cultivar, fliar feeding of wheat with fertilizers containing free amino acids resulted in grain yield increases ranging from 2.4 to 7.2% (Tab. 3). A significant yield increase compared to the control object was found after the application of Fertileader Tonic together with amino acid fertilizers: Ecovigor AA (0.30 t ha^{-1}) and Aminosol (0.33 t ha^{-1}). Grain yield gains were the result of a significant increase in ear density in these fertilizer facilities and in the weight of 1,000 grains after the application of Fertileader Tonic together with Aminosol fertilizer (Tab. 4). The effect of fertilizers containing amino acids on the number of grains per ear was not statistically confirmed. In a study by Dromantienė et al. [2013], the increase in grain yield under the influence of fertilizers with amino acids applied at the earing stage ranged from 0.10 to 6.04% (0.13–0.37 t ha^{-1}) and, according to the authors, resulted from the activation of physiological processes taking place in wheat cells. In addition, the study showed a differentiated response of wheat cultivars to amino acid fertilization in the formation of yield and its components. The largest grain yield increases under the influence of foliar fertilization were found in RGT Kilimanjaro (0.05–0.48 t ha^{-1}) and Ostka Grodkowicka (0.26–0.43 t ha^{-1}) cultivars. In the case of other old wheat cultivars, fertilizer efficiency was lower, ranging from 0.07 to 0.32 t ha^{-1}. The application of fertilizers containing amino acids in RGT Kilimanjaro wheat crop increased the ear density from 0.5 to 2.0%, the number of grains per ear from 1.0 to 4.2%, and the weight of 1,000 grains from 0.2 to 2.2%. In the case of old wheat cultivars, the increase in the value of grain yield components was in the range of 0.4 to 4.4% for ear density, number of grains per ear from 0.4 to 5.0%, and weight of 1,000 grains from 0.5 to 6.4%, respectively. Baqir and Al-Naqeeb [2019], evaluating the effect of foliar fertilization of wheat with tryptophan, lysine, glycine and cysteine, showed an increase in ear density ranging from 12.6% to 43.0%, and 1,000 grain weight from 2.3% to 12.1%. The authors further proved the superiority of tryptophan over the other amino acids in shaping the values of these traits, attributing to it a role in the construction of IAA. In the study of Kandil and Marie [2017], the increase in ear density after the application of fertilizers with amino acids averaged 7.7%, the number of grains per ear 10.8%, and the weight of 1,000 grains 12.5%.

Weather conditions prevailing in individual seasons of winter wheat vegetation had a significant effect on grain yield, ear density, number of grains per ear and agricultural harvest index (HI), while they did not differentiate the weight of 1,000 grains (Tabs 3–5). The highest grain yields, component values and harvest index were found in the 2020/2021 season characterized by the highest rainfall in the study cycle, which, moreover, significantly exceeded the rainfall needs of wheat in April–July 2021. The lowest grain yields and yield component values were obtained in the 2019/2020 season. This was probably due to the very short period of winter dormancy of plants, and the unfavorable course of rainfall and thermal conditions during spring vegetation (March–May) in 2020. In winter wheat grain production, the critical period in terms of plant water supply is the earing stage or just before earing, flowering, and then grain development [Senapati et al. 2018, Iwańska and Stępień 2019]. Thermal conditions also play an important role during this period. As reported by Wheeler et al. [2000] and Haliniarz et al. [2013], high air temperatures in June combined with a shortage of precipitation cause a reduction in grain yield by lowering the weight of 1,000 grains. The size and structure of grain yield were also determined by the interaction between wheat growing seasons and fertilizers containing amino acids. The significant effect of this factor on grain yield (Fig. 1a) and ear density (Fig. 1b) was marked in seasons with more rainfall (2019 and 2021 harvesting years). The number of grains per ear (Fig. 1c) and the weight of 1,000 grains (Fig. 1d) depended to a greater extent on the fertilizer variant than on moisture conditions, since in all years of the study the highest values of these traits were observed for wheat, in the cultivation of which Aminosol and Fertileader Tonic were applied together. A significant increase in the number of grains per ear was also found after the application of Ecovigor AA and Fertileader Tonic fertilizers, but only in years with more rainfall (2019 and 2021).

CONCLUSIONS

1. The highest grain yield was found for the contemporary cultivar RGT Kilimanjaro, averaging 7.27 t ha^{-1}, while the old winter wheat cultivars yielded 36.3 to 50.3% lower. In this group of cultivars, Nadwiślanka had the highest yield potential, while Blondynka the lowest.

2. Lower grain yields of old wheat cultivars were the result of weaker plant tillering, lower number of developed grains per ear, and weight of 1,000 grains compared to wheat grown today.

3. The application of fertilizers containing free amino acids resulted in grain yield increases ranging from 2.4 to 7.2%. A significant increase in yield was found after the application of Fertileader Tonic together with the fertilizers Ecovigor AA and Aminosol.

4. Fertilization of wheat with amino acids differentiated ear density and 1,000 grains weight. Significant increases in the values of these traits were found with the combined application of Fertileader Tonic and Aminosol fertilizers, and in the case of ear density also after the application of Ecovigor AA fertilizer.

5. Fertilizers with amino acids or their mixtures significantly differentiated the size and structure of grain yield of RTG Kilimanjaro wheat. The reaction of the old varieties was definitely weaker. In case of Ostki Grodkowicka, fertilization differentiated the number of ears and the weight of 1000 grains, in the case of Square Head Grodkowicka the grain yield and number of ears, and in the case of Blondynka only the weight of 1000 grains. Other cultivars showed no reaction to fertilization.

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