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Effect of Magnesium and Biostimulant Fertilization on the Consumption Value and Safety of Potato Tubers After Long-Term Storage

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Abstract: The primary use of the potato is direct consumption. The classification of potatoes into consumption type is made on the basis of consumption evaluation of hydrothermally treated tubers. Nutrient deficiency in the soil, including Mg, contributes to the inhibition of potato growth and development and negatively affects the cooking characteristics of the tubers. Magnesium and biostimulants are responsible for plant nitrogen management. Thus, it is necessary to control the content of harmful nitrates and toxic nitrites in tubers. In potato production, it is also important to maintain appropriate conditions during storage. The purpose of this study was to determine the effect of mineral fertilization with magnesium and a biostimulant preparation during cultivation of edible potato and long-term storage on the traits determining utility-consumption type and the content of harmful nitrogen compounds in tubers. The study was conducted using the early potato variety Satina. In a three-year (2015-2017) three-factor experiment: evaluation date (immediately after harvest and after six months of storage), soil fertilization with mineral magnesium (0, 30, 60, 90 kg MgO ha^{-1}), application of an amino acid biostimulant (0, 1.5, 3.0 l ha^{-1}), five consumption traits of tubers after cooking determining the utility-consumption type of potato were determined. In addition, the consumer safety of the potato was determined based on the nitrate and nitrite content of the tubers. The tendency to overcook tubers significantly depended on all the factors used during potato cultivation. In contrast, the texture and structure of tuber flesh after cooking depended only on mineral fertilization with magnesium. The flesh of the tubers after cooking was most tender (1.0 pt) and firm (1.4 pt) after the application of 60 and 90 kg MgO ha^{-1}, respectively. The moisture level of the flesh after cooking was significantly influenced by the interaction of magnesium fertilization with the biostimulant preparation. The factors of the experiment did not modify the utility-consumption type (B/A), while there was a change in the type in relation to that specified by the grower - general utility (B). The applied cultivation technology and long-term storage did not deteriorate the consumer safety of tubers (<200 mg kg^{-1}) in terms of NO_3^- (max. 112.1 mg kg^{-1}) and NO_2^- (max. 1.08 mg kg^{-1}) contents. Organoleptic traits: mealiness, moisture and flesh structure were significantly positively related to nitrate and nitrite content of tubers immediately after harvesting and to nitrite concentration after long-term storage.

Keywords: edible potato; consumption value; magnesium; biostimulant; nitrate; nitrite; storage

1. Introduction

Potato, being one of the world's major crops, is a staple food for many people [1–5]. It provides the body with many valuable substances, such as protein, fiber, vitamins and minerals. It is also a rich source of compounds that exhibit antioxidant activity [6–9]. The primary use of the potato is direct consumption. Potato is also used in processing to produce refined products, starch and alcohol [9–12].

The intended use of the edible potato depends mainly on the variety, whose tubers differ in shape, flesh and skin color, mesh depth, culinary type and chemical composition. The classification of potatoes into a particular type of use is made on the basis of consumption evaluation, carried out on hydrothermally treated tubers [13–17].

Potato quality is determined by environmental conditions and cultivation technology [18–22]. An increase in the quality of potato tubers should go hand in hand with maximizing production per unit area while maintaining applicable environmental standards [23,24]. Achieving this goal is possible through the introduction of economically viable, ecologically sustainable and socially acceptable means of cultivation [25]. Measures that meet the aforementioned conditions include magnesium fertilizers and preparations that stimulate plant growth and development (biostimulants) [26,27]. Magnesium, as a major component of chlorophyll, controls many processes related to photosynthesis and assimilate production in plants [28–30]. Its absence contributes to the stunting of potato growth and development and negatively affects the tubers' culinary characteristics [31]. On the other hand, biostimulants are compounds responsible for the activation and control of many biochemical processes [32]. In addition, magnesium similarly to biostimulants increases plant resistance to stress, influences their nitrogen management and enhances nitrogen uptake by plants [33,34]. Therefore, potatoes harvested by technology based on mineral fertilization with magnesium and biostimulants should be controlled for the content of harmful nitrogen compounds. In potato tubers, these are mainly anti-nutritive nitrates, the content of which is a basic indicator of the release of edible potatoes for sale [27]. Potato tubers also contain minor amounts of toxic nitrites. The occurrence of nitrates in exceeded amounts is hazardous, because they are precursors of highly toxic nitrites, which result in methemoglobinemia or vitamin A deficiency. When nitrites enter the blood, they bind hemoglobin, forming methemoglobin, which can result in serious poisoning, even leading to death, if consumed excessively [35]. According to Commission Regulation (EC) No. 1822/2005 of November 8, 2005, the nitrate content of potatoes should not exceed 200 mg kg^{-1} in tubers (food). Meanwhile, the FAO/WHO Expert Committee has set the maximum acceptable daily intake (ADI) for nitrate at 0-3.7 mg and for nitrite at 0-0.7 mg per kilogram of human body weight.

Genetic factors and storage time and conditions are also important for tuber quality [9,36–38]. Regardless of the destination of tubers from the total weight of potatoes, every year more than half of the harvest is stored for up to 9 months. It is therefore extremely important to maintain appropriate conditions throughout the storage period, which should be adapted to the direction of use of the potato. Varieties intended for consumption should be stored at a constant temperature of +4°C and 95% relative humidity. Failure to maintain the required storage parameters may result in deterioration of tuber quality [3,39–41].

The purpose of this study was to determine the effect of mineral fertilization with magnesium and a biostimulant preparation during cultivation of edible potato and long-term storage on traits determining utility-consumption type of potato and the content of harmful nitrogen compounds in tubers.

2. Materials and Methods

The research material was a very popular early potato variety on the European market - Satina, classified as utility-consumption type B. A three-factor field experiment (2015 -2017) was carried out using the randomized sub-block method at the Research Station in Mochełek (Kujawsko-Pomorskie Voivodeship) belonging to the Bydgoszcz University of Science and Technology (53° 13'N, 17° 51'E).

Experimental factors:

- Evaluation date (A); (immediately after harvest, after 6 months of storage)
- Magnesium fertilization (B); MgO doses (0, 30, 60, 90 kg ha^{-1})
- Application of biostimulant (C); (0, 1.5, 3.0 l ha^{-1})

Mineral magnesium was applied in soil before planting potatoes in the form of 16% magnesium sulfate ($MgSO_4$) along with fertilization with nitrogen, phosphorus and potassium at rates of: 100 kg N ha^{-1} (ammonium nitrate - 34%); 120 kg K_2O ha^{-1} (potassium sulfate - 50%); 80 kg P_2O_5 ha^{-1} (triple superphosphate - 46%). Biostimulant (Protifert LMW) was applied three times during the potato

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growing season: at plant growth of 15 cm, immediately after flowering and 2 weeks after flowering. Protifert LMW contains in its composition an organic peptide and amino acids. It improves plant nutrition, which is due to the complexing (chelating) properties of amino acids with micro- and macroelements. It exhibits anti-stress effects by strengthening plant resistance to diseases and pests and improving water balance. In addition, it increases the effectiveness of protective measures and improves soil structure.

Potatoes were planted at the end of April using a mechanical planter. The experiment was set up in plots of 33.6m^2 with a row spacing of 0.75 x 0.35 m. 22.4m^2 was used for harvesting. The forecrop was cereals. In the fall, manure was applied at 25Mg ha^{-1}.

Plant protection and agrotechnology included treatments in accordance with the principles of optimal potato cultivation. The tubers were harvested when they reached full maturity (September/October). During harvest, tuber samples were taken for direct post-harvest evaluation (10 kg) and samples for the storage experiment (10 kg) from each combination of field experiments. Before the samples were placed in the climate chamber, they were weighed. Tuber samples of each variety were subjected to the ripening process. For this purpose, edible potato samples were put in a climate chamber where the air temperature was 18 °C and humidity was 95% for the first 10 days. After that, the air temperature was progressively lowered to 4 °C. The storage process was carried out in a 2x2x3.8m polypropylene panel storage chamber (Thermolux Refrigeration Air Conditioning, Raszyn, Poland) in the Institute of Agri-Foodstuff Commodity of Bydgoszcz University of Science and Technology. In order to stimulate the temperature of the environment and reduce heat loss, the experimental chamber uses 20mm thick foam insulation material. Above that, the chamber is equipped with an automatic humidity maintenance system.

Table 1 shows the properties of the soil immediately before the establishment of the field experiment. The pH value in 1 M KCl was determined by potentiometric method [42]. Organic carbon content was determined by the Tiurin method in mineral soil samples [43]. The content of total nitrogen in the dried samples was determined by the Kjeldahl distillation-titration method according to test procedure (PB) 37 ed. 3 dated 15.10.2009 [44]. The content in the soil of bioavailable P [45] and K [46] (both measured by the Egner-Riehm method) and Mg (determined by the Schatschabel method [47]) was marked according to the standards.

The average monthly air temperature and total precipitation for the years of the study (2015-2017) and from a multi-year period (1996-2014) are shown in Table 2.

Table 1. Soil parameters before the field experiment (2015-2017 average).

Parameter	Unit	Amount	Abundance
pH H2O	-	6.6	Slightly acidic
pH KCl	-	6.1	Slightly acidic
Organic carbon	[g kg^{-1}]	8.75	-
Total nitrogen	[g kg^{-1}]	0.78	-
Absorbable forms of phosphor	[mg kg^{-1}]	27.0	Poor
Absorbable forms of potassium	[mg kg^{-1}]	49.0	Very poor
Absorbable forms of magnesium	[mg kg^{-1}]	23.0	Very poor

Table 2. Average monthly air temperature and total precipitation in 2015-2017 and in the multi-year period 1996- 2014.

	Air temperature (°C)				Rainfall (mm)			
Month	**2015**	**2016**	**2017**	**1996-2014**	**2015**	**2016**	**2017**	**1996-2014**
April	7.5	8.3	6.8	8.1	15.6	28.7	40.8	28.7
May	12.4	14.7	13.4	13.2	21.6	51.4	56.3	61.1
June	15.6	17.7	16.8	16.3	33.0	98.1	54.3	53.1
July	18.5	18.3	17.7	18.7	50.4	133.8	118.9	87.1
August	20.9	16.4	14.3	17.8	20.3	55.3	19.4	67.0

September	13.8	14.3	13.0	13.0	52.4	19.4	78.4	66.5
Average	14.8	15.0	13.7	14.5	32.2	64.5	61.4	60.6

Throughout the 2015 growing season, except for August and September, air temperature was lower than in the multi-year period. There were also slight deviations in precipitation totals from the multi-year totals throughout the 2015 growing season. In contrast, in each month of the growing season of 2016 and 2017, air temperatures were very similar to the multi-year period. Excessive precipitation was recorded in June as well as July in both 2016 and 2017.

The sensory assessment of potato tubers was performed in the Institute of Agri-Foodstuff Commodity of Bydgoszcz University of Science and Technology based on the methodology adopted by the European Association for Potato Research (EAPR) in the form of guidelines of the Institute of Plant Breeding and Acclimatization in Jadwisin [48]. The cooking procedures were designed to be similar to how consumers handle potatoes. Assessment of cooked tubers was carried out directly after they were peeled and rinsed with water. Clean tubers were placed in a pot of boiling, unsalted water. They were then cooked covered until tender (their softness was checked by pricking them with a fork). After cooking tubers were placed on a tray, each of the ten members of the committee examined them for sensory predisposition according to the ISO standard [49]. In cooked tubers the following features were assessed according to Zgórska et al. [50]:

- tendency to overcook (1pt - unchanged surface, 4 pts - overcooked surface)
- texture (1pt - firm, 4pts - soft)
- mealiness (1pt - not floury, 4pts - loose)
- moisture (1pt - moist, 4pts - dry)
- flesh structure (1pt - tender, 4pts – rough)

In addition, the utility-consumption type was determined by comparing the scores obtained with the requirements according to the table 3.

Table 3. Requirements defining utility-consumption type of potato according to Zgórska et al. [50].

Utility-consumption type	Tendency to overcook	Texture	Mealiness	Moisture	Flesh structure
A	1	1	1-2	1-2	1
B	1-2	1-2	2	2	1-2
C	3	2-3	3	3	2-3
D	4	3-4	4	4	3-4

The cooked tubers were cut and frozen. The frozen potato samples were kept at -18 °C. The samples were then lyophilized (using CHRIST ALPHA 1-4 LSC, Osterode am Harz, Germany) and ground (particle size 0.3-0.5 mm) using an Ultra-Centrifuge Retsch ZM 100 laboratory grinder (Retsch, Germany). The milled samples were placed in sealed bags and stored in the dark until laboratory testing. In the material prepared in this way, the content of nitrates and nitrites was determined.

Two grams of freeze-dried potatoes were mixed with 50 ml of a 1% solution of $KAl(SO4)_2$ (Merck, Germany) and extracted well. The extraction was conducted for 1 hour with a shaker (IKA KS, Model 130 Basic - Staufen, Germany). Samples were filtered over Whatman filter paper No. 4. Ten milliliters of a 60% solution of $Al_2(SO_4)_3$ (Acros Organics, USA) was added to the filtrate and mixed directly before determination. Nitrate content was determined using KNO_3 standard curves (Merck, Germany). Deionized water was used at each stage of analytical testing. The CX-721 multifunctional computerized apparatus (Elmetron, Poland) was used for the determination of nitrate content by the ion-selective potentiometric method. The measurement principle is based on the linear dependence of the electrode potential on the logarithm of ion activity in solution. The device was provided with a nitrate electrode, a double-junction reference electrode (fill the outer chamber with 0.02 M solution of $(NH_4)_2SO_4$ (Merck, Germany)), a specific ion meter and a pH/milovolt (mV) meter with a reading accuracy of 0.1 mV. The limit of determination was set at 30 mg kg^{-1}, and the measurement error was about 15%, according to the matrix of the sample being measured. NO_2^- ions were determined after oxidation to NO_3^- in a previously prepared sample of this extract according to the method described above. For this purpose, one ml of 30% H_2O_2 (Merck, Darmstadt, Germany) was added and the ionometric potential was measured after five minutes. Nitrate and nitrite contents were expressed in FW (mg kg^{-1} f. m.).

The results obtained from the three-year study were subjected to statistical calculations and significant differences were assessed using Tukey's multiple confidence intervals for a significance level of $\alpha = 0.05$. Analysis of variance of the data was calculated using Statistica® software. To obtain a synthetic picture of the overlapping relationships between the studied characteristics, a simple correlation analysis (Pearson's) was performed. Tests were carried out with three (field) and two (laboratory) replications. Averages of results as well as standard deviation are shown in tables.

3. Results and Discussion

As can be seen from the data in Table 4, the tendency of the tubers of the Satina variety to be overcooked significantly depended only on the factors used in the cultivation technology - fertilization with magnesium and biostimulant. Potato tubers from control objects were characterized by a slightly cracked surface, with an average of 2.0 points. On the other hand, each of the applied doses of magnesium and biostimulant reduced the tendency of the tuber flesh to be overcooked compared to the control. Significantly positive influence on this distinguishing feature of the consumption value was exerted by magnesium in the amount of 90 kg MgO ha^{-1} and Protfert in the amount of 3 l ha^{-1}. The tendency to overcook the flesh surface is related to the saturation of cell walls with pectic substances - protopectin and water-soluble pectin, which confirms the influence of the chemical composition of tubers on flesh overcooking [51,52]. The overcooked surface of cooked potatoes is inextricably linked to another characteristic of culinary value - mealiness. The results of our own study did not confirm such a tendency, as no correlation was shown between the tendency to overcook and mealiness regardless of the test date (Table 5 and 6). There was also no effect of the experimental factors on the level of mealiness of the flesh of the tubers of the studied variety (Table 4 and 7).

Table 4. Average values for quality traits determining the utility-consumption type of tubers of Satina variety directly after harvest.

MgO fertilization doses (kg ha^{-1}) (B)	Potato tuber evaluation date (A)				
	Tendency to overcook	Texture	Mealiness	Moisture	Flesh structure
Without biostimulant application - control (C)					
0	2.0±0.50	1.9±0.10	1.1±0.12	1.5±0.00	1.5±0.00
30	1.8±0.25	1.7±0.29	1.1±0.12	1.5±0.00	1.5±0.00
60	1.5±0.50	1.6±0.17	1.2±0.17	1.3±0.25	1.5±0.25
90	1.3±0.25	1.6±0.15	1.1±0.12	1.3±0.25	1.1±0.17
Average	1.6±0.00	1.7±0.10	1.1±0.00	1.4±0.10	1.4±0.06
Biostimulant application - 1.5 l ha^{-1} (C)					
0	1.9±0.40	1.8±0.25	1.1±0.10	1.5±0.50	1.5±0.50
30	1.8±0.25	1.6±0.15	1.0±0.00	1.5±0.50	1.2±0.29
60	1.8±0.25	1.3±0.25	1.0±0.00	1.0±0.00	1.0±0.00
90	1.5±0.00	1.8±0.25	1.0±0.00	1.0±0.00	1.0±0.00
Average	1.7±0.10	1.6±0.20	1.0±0.06	1.3±0.25	1.2±0.17
Biostimulant application - 3.0 l ha^{-1} (C)					
0	2.3±0.25	2.0±0.00	1.2±0.12	1.5±0.00	1.5±0.50
30	2.0±0.00	1.7±0.00	1.0±0.00	1.5±0.15	1.3±0.15
60	1.8±0.25	1.5±0.50	1.0±0.00	1.0±0.00	1.3±0.00

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90	1.3±0.25	1.5±0.50	1.0±0.00	1.0±0.00	1.0±0.00
Average	1.8±0.20	1.7±0.25	1.0±0.06	1.3±0.06	1.3±0.10
Average					
0	2.0±0.35	1.9±0.10	1.1±0.06	1.5±0.20	1.5±0.00
30	1.8±0.15	1.7±0.12	1.0±0.06	1.5±0.20	1.3±0.10
60	1.7±0.00	1.4±0.25	1.1±0.06	1.1±0.10	1.3±0.10
90	1.3±0.15	1.6±0.30	1.0±0.06	1.1±0.10	1.0±0.06
Average	1.7±0.10	1.7±0.21	1.1±0.00	1.3±0.10	1.3±0.01

$NIR_{0.05}$ (Tukey test)

Tendency to overcook :

A - ns[1] B - 0.31 C - 0.16 B/A - ns A/B - ns B/C - ns A/C - ns C/B - ns
B/C - ns

Texture :

A - ns B - 0.23 C - ns B/A - ns A/B - ns B/C - ns A/C - ns C/B - ns
B/C - ns

Mealiness :

A - ns B - ns C - ns B/A - ns A/B - ns B/C - ns A/C - ns C/B - ns
B/C - ns

Moisture :

A - ns B - ns C - ns B/A - 0.22 A/B - 0.49 B/C - ns A/C - ns C/B - ns
B/C - ns

Flesh structure:

A - ns B - 0.13 C - ns B/A - ns A/B - ns B/C - ns A/C - ns C/B - ns
B/C - ns

[1]ns – non-significant

Table 5. Linear correlation analysis (Pearson) of the studied characteristics of the Satina potato variety after harvest.

	Tendency to overcook	Texture	Mealiness	Moisture	Flesh structure	NO_3^-
Texture	0.526					
Mealiness	ns	0.429				
Moisture	ns	0.673	0.412			
Flesh structure	0.379	0.576	0.510	0.729		
NO_3^-	ns	ns	0.492	0.569	0.562	
NO_2^-	ns	ns	0.555	0.545	0.602	0.838

indicates that the correlation is significant at the 0.05 probability level >0.334; indicates that the correlation is significant at the 0.01 probability level >0.235

Table 6. Linear correlation analysis (Pearson) of the studied characteristics of the Satina potato variety after long term storage.

	Tendency to overcook	Texture	Mealiness	Moisture	Flesh structure	NO_3^-
Texture	0.446					
Mealiness	ns	0.473				
Moisture	ns	0.339	ns			
Flesh structure	0.586	0.566	ns	0.707		
NO_3^-	0.430	0.390	0.342	0.588	0.472	
NO_2^-	ns	ns	0.318	0.639	0.387	0.818

indicates that the correlation is significant at the 0.05 probability level >0.334; indicates that the correlation is significant at the 0.05 probability level >0.235

The texture of cooked tubers is one of the most important characteristics affecting consumer acceptance of a variety. The tested Satina is a variety with slightly firm flesh. Tests conducted confirmed its genetic predisposition in this regard and of the experimental factors used, only magnesium fertilization modified this trait (Table 4). It should be noted that each of the applied doses of magnesium changed the texture of the tuber flesh to more compact. The most compact flesh was characterized by tubers after the application of a dose of 60 kg MgO ha^{-1} (average 1.4 pt). According to Pyryt and Kolenda [53], the texture of tuber flesh depends mainly on genetic conditions. However, Grudzińska and Czerko [51] report that the consistency of potato tubers, regardless of variety, ranging from firm to spreading, is closely related to the chemical properties of the raw material and technological parameters in its production process. The texture of potatoes after cooking depends on the content of: cellulose, pectin, hemicellulose and lignin in raw tubers. The content of these substances varies depending on the length of the growing season. The longer the growing season, the higher the content of cellulose, hemicellulose and lignin in potatoes [54]. In addition, the texture of potatoes depends largely on the heat treatment, that is, the temperature and cooking time [53].

The timing of the tests had no significant effect on the tubers' cooking characteristics: tendency to overcook, texture and mealiness (Table 4 and 7).

Table 7. Average values for quality traits determining the utility-consumption type of tubers of Satina variety after long-term storage.

MgO fertilization doses (kg ha^{-1}) (B)	Potato tuber evaluation date (A)				
	Tendency to overcook	Texture	Mealiness	Moisture	Flesh structure
Without biostimulant application - control (C)					
0	1.9±0.10	2.1±0.10	1.2±0.06	1.8±0.00	1.8±0.00
30	1.8±0.12	1.8±0.12	1.1±0.06	1.8±0.25	1.4±0.12
60	1.6±0.06	1.6±0.17	1.3±0.00	1.6±0.15	1.4±0.10
90	1.5±0.15	1.6±0.15	1.2±0.20	1.4±0.10	1.2±0.10
Average	1.7±0.06	1.8±0.00	1.2±0.10	1.6±0.12	1.4±0.06
Biostimulant application - 1.5 l ha^{-1} (C)					
0	2.3±0.29	2.0±0.06	1.2±0.15	1.8±0.25	1.8±0.25
30	1.8±0.10	1.8±0.12	1.1±0.12	1.5±0.10	1.5±0.15
60	1.9±0.12	1.8±0.17	1.2±0.15	1.2±0.10	1.2±0.00
90	1.5±0.00	1.3±0.12	1.1±0.17	1.3±0.25	1.2±0.21
Average	1.9±0.10	1.7±0.06	1.1±0.06	1.4±0.06	1.4±0.17
Biostimulant application - 3.0 l ha^{-1} (C)					
0	2.0±0.00	2.3±0.12	1.3±0.06	1.3±0.25	1.5±0.20
30	1.8±0.25	1.8±0.12	1.1±0.12	1.4±0.12	1.5±0.00
60	1.7±0.15	1.8±0.12	1.1±0.23	1.7±0.20	1.5±0.06
90	1.5±0.50	1.5±0.29	1.1±0.15	1.4±0.12	1.3±0.25
Average	1.7±0.15	1.8±0.06	1.2±0.06	1.4±0.10	1.4±0.00
Average					
0	2.1±0.06	2.1±0.06	1.2±0.06	1.6±0.20	1.7±0.00
30	1.8±0.15	1.8±0.25	1.1±0.10	1.5±0.06	1.5±0.06
60	1.7±0.00	1.7±0.10	1.2±0.00	1.5±0.06	1.4±0.06
90	1.5±0.20	1.4±0.06	1.1±0.12	1.4±0.06	1.2±0.15
Average	1.8±0.06	1.8±0.06	1.2±0.06	1.5±0.00	1.4±0.06

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$NIR_{0.05}$ (test Tukey'a)
According to the Table 4

Moisture content of tuber flesh after cooking is a consumption trait that largely depends on the weather conditions prevailing during the potato growing season [55–57] and storage conditions and time [37]. According to Pardo et al. [58], potatoes with higher moisture content have lower firmness, which negatively affects the taste of cooked tubers. Our study showed a significant change in the value of this trait under the interaction of the evaluation date and the dose of magnesium fertilization (Table 4 and 7). Potato tubers evaluated immediately after harvest from objects fertilized with doses of 60 and 90 kg MgO ha^{-1} showed higher moisture content - 1.1pt compared to tubers from the control object (without Mg application) after six-month storage - 1.6pt. According to Hunjek et al. [37], the long-term storage period significantly affects the tested sensory characteristics of cooked tubers, including moisture content. According to the authors, the longer the storage period, the wetter the flesh of the tubers, with a slight change in the first storage period.

In our study, the flesh structure of tubers after cooking significantly depended only on mineral magnesium fertilization (Table 4). Each of the applied doses of magnesium clearly affected the change in flesh structure. Regardless of the date of the study, the dose of 90 kg MgO ha^{-1} had significantly the greatest effect in this regard (Table 4 and 7). This is confirmed by the studies of many authors [59–61] according to whom the distinguishing features of the cooking value depend largely on agrotechnical treatments. They also emphasize the influence of genetic conditions and weather conditions during potato vegetation. Our study also showed a highly significant relationship between flesh structure and the other analyzed tuber consumption value traits evaluated immediately after harvesting ($p<0.01$) (Table 5). In contrast, after storage, there was no relationship between structure and mealiness (Table 6).

Determined and described sensory characteristics of tuber flesh determine the type of utility-consumption edible potato. The values of 5 quality characteristics obtained in our own research indicate that the Satina variety was classified as a general utility/salad type (B/A) (Table 8). On the other hand, according to the breeder Solana Polska Sp. z o .o, the Satina variety is classified as general utility type (B). Long-term storage did not change the utility-consumption type of the tested Satina variety (Table 8). This indicates that the consumption-utility type is most influenced by the conditions during potato cultivation [62].

Table 8. Values of distinctive features of consumption quality of potato tubers of Satina variety directly after harvest and after long term storage.

Tendency to overcook		**Texture**		**Mealiness**		**Moisture**		**Flesh structure**		**Utility-consumption type**	
a/h	**a/s**	**a/h**	**a/s**	**a/h**	**a/s**	a/h	a/s	a/h	a/s	a/h	a/s
1.7	1.8	1.7	1.8	1.1	1.2	1.3	1.5	1.3	1.4	B/A	B/A

*a/h – after harvest; *a/s – after long term storage

The obtained values of consumption quality indicators in our study show that the applied cultivation technology and long-term storage period did not change the culinary type of the studied variety (Table 8). Similar results were obtained by Zarzecka et al. [63], who showed no effect of using biostimulants on the culinary type of three potato varieties. Of a different opinion are Zarzecka et al. [62] in their study, whose utility-consumption type changed after the application of a biostimulant preparation to the soil. However, it should be remembered that consumer preferences for the utility-consumption type of potato are closely related to the region of residence [13]. Therefore, it is necessary to cultivate varieties in a given region in accordance with consumer preferences, using such a system of cultivation technology that there is no change in functional type under its influence [64–66].

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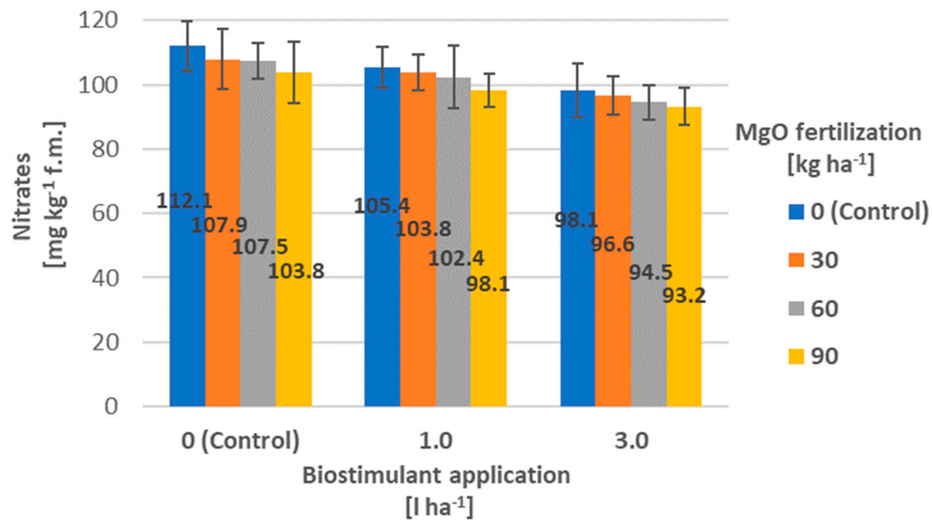
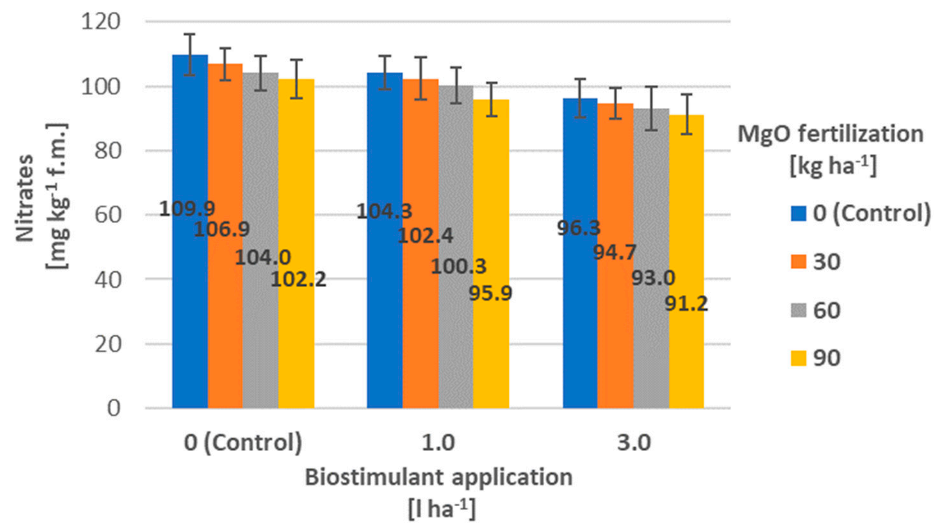
Regardless of the factors used in the experiment, tubers of the Satina variety did not exceed the set standard (<200 mg kg^{-1} f. m.) of nitrate content (Figures 1A and B). The permissible daily standard of nitrite intake of 42 mg at an average consumer weight of 60 kg was also not exceeded. This confirms the genetically low propensity of the tested variety to accumulate nitrates and nitrites. It should be noted that the nitrate content of tubers depends on the genetic conditions of the potato [67]. On the other hand, the applied magnesium fertilization and the spraying of plants with a biostimulant preparation during potato cultivation caused a significant reduction in the content of both antinutritional nitrates and toxic nitrites in tubers compared to tubers from the control object. In this regard, the highest doses of magnesium - 90 kg MgO ha^{-1} (98.0 mg kg f.m. NO_3^-, 0.94 mg kg f.m. NO_2^-) and biostimulant preparation - 3 l ha^{-1} (93.8 mg kg f.m. NO_3^-, 0.91 mg kg f.m. NO_2^-) had the best effect (Figures 1A and 2A).



(**a**)

NIR$_{0.05}$ (Tukey test): A – ns (non-significant); B – 1.65; C – 1.55; A/B – ns; B/C – ns; A/C - ns

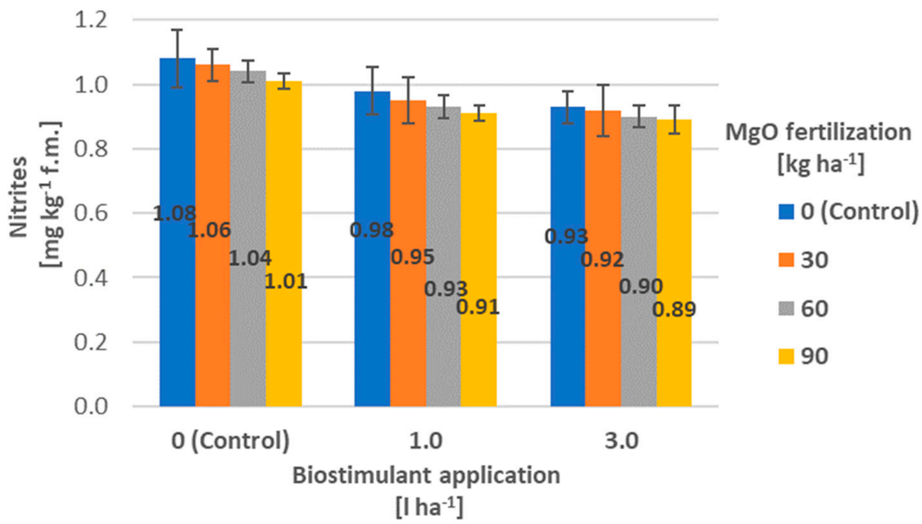


(**b**)

Figure 1. Study of nitrate content in cooked tubers: **(A)** directly after harvesting potatoes, **(B)** after long-term storage of potatoes.

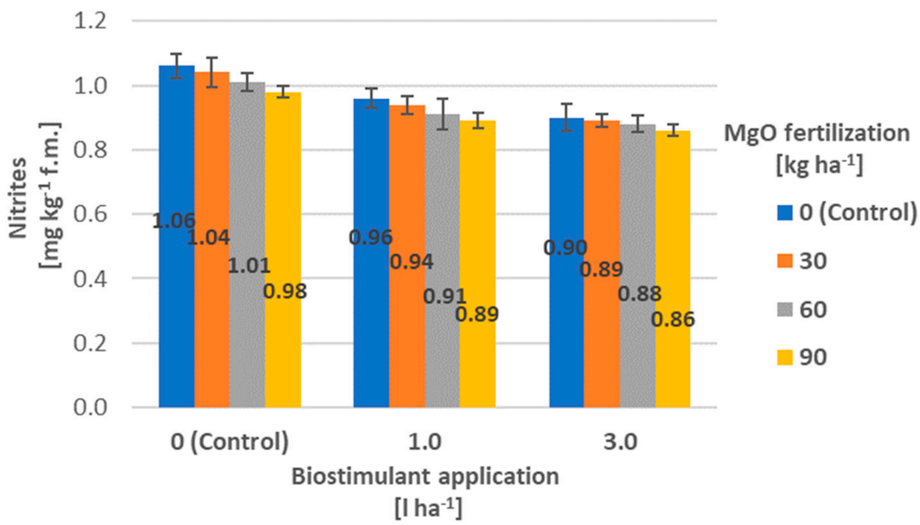
The positive effect of magnesium-containing fertilizers and biostimulants on nitrate concentration in potato tubers has been reported by many authors [27,32,68]. It was also noted that magnesium fertilization and biostimulant application had similar effects on nitrite accumulation in tubers. The application of Mg fertilizers is often neglected in the management of plant chemical components. Magnesium plays an important role in controlling the biological use and distribution of nitrogen in crops and the environment. Mg deficiency, on the other hand, reduces the activity of nitrate reductase and glutamine synthetase, thereby reducing the absorption and utilization of nitrogen by plants [69]. In addition, amino acid preparations do not nourish plants directly, but their action is based on stimulation of specific physiological processes in the plant, so their importance and role in plant growth and development is important [70]. By supplying the plant with amino acids from outside, the plant does not have to waste energy on their production. This allows the plant to use the energy for faster and better growth. This allows the plant to increase productivity and improve quality [71].

Moreover, potato tubers that contained higher amounts of nitrates also contained higher amounts of nitrites, which was confirmed by positive high correlation coefficients between the studied compounds both after harvest and after storage: r=0.838; r=0.818 respectively (Table 5 and 6). A study by other authors [27] also found a positive correlation between nitrate and nitrite contents in edible potato tubers.



(a)

NIR0.05 (Tukey test): A – ns (non-significant); B – 0.006; C – 0.010; A/B – ns; B/C – ns; A/C - ns



(b)

Figure 1. Study of nitrite content in cooked tubers: **(A)** directly after harvesting potatoes, **(B)** after long-term storage of potatoes

It is known that the chemical composition of potato tubers changes during storage. The changes involve both nutrient content and harmful compounds [27,37,72,73]. In our study, the content of harmful compounds (nitrates and nitrites) in tubers did not change after long-term storage (Figures 1B and 2B). In order for there to be no transformation in the chemical composition of tubers during storage, storage conditions should be adjusted to the requirements in accordance with the potato's functional qualities [27,40,74]. The own tests confirmed such a relationship, which testifies to well-chosen thermal and humidity conditions throughout the storage period. It should be noted that constant conditions were used throughout the storage cycle: T - 4°C and RH - 95%. The obtained correlation coefficients (P>0.01 and P>0.05) between the organoleptic characteristics of cooked tubers and the content of harmful compounds (NO_3^- and NO_2^-) in potatoes indicate a strong influence of the chemical composition of the flesh on its consumption quality [72,75–77]. It was shown that all of the post-storage consumption value discriminators analysed in the study depended on nitrate content (Table 6). On the other hand, organoleptic traits: mealiness, moisture content and flesh texture significantly positively depended on nitrate and nitrite content of tubers immediately after harvesting and on nitrite concentration after long-term storage (Table 5 and 6). Changes in sensory characteristics of tubers after cooking show a significant evolution not only from the cooking method but also from potato production technology and the content of chemical components [38,75,78–80].

4. Conclusions

The tendency to overcook tubers significantly depended on all applied factors during potato cultivation. In contrast, the texture and the structure of the tuber flesh after cooking depended only on mineral fertilization with magnesium. After the application of a dose of 90 kg MgO ha^{-1}, the flesh of tubers after cooking was more firm and after the application of 60 kg MgO ha^{-1} it was perfectly tender. There was no effect of the experimental factors on the level of mealiness. The level of moisture content of the flesh after cooking was significantly affected by the interaction of magnesium fertilization with the biostimulant applied together. The factors of the experiment did not modify the utility-consumption type (B/A), while there was a change in the type in relation to that specified by the breeder - general utility (B). Regardless of the factors used in potato cultivation, the tubers after cooking of the Satina variety were safe for the consumer, both after harvest and after storage. The standards for NO_3^- and NO_2^- in potato tubers were not exceeded. The application of magnesium fertilization and the application of a biostimulant containing amino acids in the composition caused a significant reduction in the content of both anti-nutritive nitrates and toxic nitrites in the cooked tubers. Organoleptic traits: mealiness, moisture and flesh structure were significantly positively related to the content of nitrates and nitrites in tubers immediately after harvesting and to the concentration of nitrites after long-term storage.

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