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ORIGINAL PAPER

ORGANOLEPTIC CHARACTERISTICS AND THE TOTAL GLYCOALKALOID CONTENT OF EDIBLE POTATO TUBERS DEPENDING ON A CULTIVATION TECHNOLOGY AND STORAGE*

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Abstract

Criteria for the selection of edible potato varieties are such characteristics as the skin and flesh color, palatability and the tendency of the flesh to darken, which are subjectively evaluated by the consumer, as well as the content of undesirable substances like solanine. The quality of the edible potato depends primarily on the environmental conditions and cultivation technology. Magnesium has a considerable influence on the size and quality of the potato tuber yield. If potato plants are grown under stress conditions, a biostimulant should be used. The purpose of the research was to determine the influence of magnesium, application of biostimulant and storage time on organoleptic properties of potato tubers of the edible variety called Gala as well as the total content of glycoalkaloids (TGA) in tubers. The experimental factors were: assessment date (immediately after harvest as well as after 6 months of storage in 4ºC and RH 95%), magnesium fertilization (0, 30, 60, 90 kg ha^{-1}), biostimulator application (0, 1.5, 3.0 l ha^{-1}). The study showed that the application of magnesium during the potato growing season caused a change in the intensity of tuber flesh color to a more yellow color and increased the content of TGA. The greatest effect in this regard was obtained with the dose of 90 kg MgO ha^{-1}. In addition, the application of magnesium reduced the darkening processes of both raw and cooked tubers. The best results in this regard were obtained after the application of magnesium in soil at 30 and 60 kg ha^{-1}. The application of the biostimulant had a positive effect on the distinguishing features of the consumption value: taste and smell. The best taste and neutral

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smell were obtained by potato tubers from objects where the biostimulant was applied at a dose of 1.5 l ha^{-1}. Application of the biostimulant increased the TGA content in tubers. Long-term storage generally deteriorated the quality of the Gala potato variety tubers in terms of all the tested organoleptic characteristics and increased the TGA content.

Keywords: edible potato, consumption value, oxidative potential, magnesium, biostimulant, storage, solanine

INTRODUCTION

Potato, along with wheat, rice and corn, is ranked among the most important crops. Owing to the high nutritional value of potato tubers, the plant continues to be a dietary staple food for many people (Devaux et al. 2014, Alamar et al. 2017). Consumers seek on the market varieties with good palatability. Characteristics such as the flesh and skin color and the tendency of the flesh to darken are also criteria for their selection. However, it should be remembered that the sensory properties of tubers are assessed by consumers subjectively (Wszelaczyńska et al. 2017).

Potato quality is influenced by the environmental conditions and cultivation technology. No less important factors are genetic predispositions, as well as duration and conditions of storage (Rytel et al. 2008, Zgórska, Grudzińska 2012). Among the elements of great importance for the size and quality of the potato tuber yield there is the element magnesium. Its absence in the plant causes the inhibition of the plant's growth and development, and negatively affects the culinary characteristics of the tubers (Osowski et al. 2017). The potato quality is also influenced by the use of biostimulants in its cultivation. Biostimulants are responsible for the activation and control of many vital processes. They also affect the nitrogen use by crop plants (Sawicka et al. 2016).

There are specific requirements for potatoes intended for direct consumption. Potato tubers of edible varieties are evaluated in terms of morphological, physiological and organoleptic characteristics (Leszczyński 2000, Lisińska 2006, Zgórska, Grudzińska 2012). Table potatoes should be characterized by shapely tubers with smooth skin and only slightly darkening flesh (on a scale of 9: raw flesh >6.5 and after cooking >7.5) – Zgórska, Grudzińska (2012), Wszelaczyńska et al. (2017). They should also be characterized by good taste and neutral smell. The high quality of potatoes is also determined by the nutritional value of the tubers and the low content of undesirable components (Lisińska 2006, Zarzecka, Gugala 2011, Wszelaczyńska et al. 2013). The main components affecting the safety and taste of potato tubers are glycoalkaloids (α- and β-solanine, chaconin and leptin) – Ginzberg et al. (2009), Haase (2010), Rytel (2012). Their accumulation in tubers is determined by the genetic composition of a potato plant, the climate and soil conditions, cultivation technology and even the post-harvest treatment of tubers

(Şengül et al. 2004, Machado et al. 2007, Tajner-Czopek et al. 2008, Wszelaczyńska et al. 2020). Due to their high toxicity, the U.S. Food and Drug Administration (FDA) has set the maximum permissible total content of glycoalkaloids in potatoes at 200 mg kg $^{-1}$ fresh weight (FW) and the intake level at 1 mg kg $^{-1}$ body weight. It is also important to note that the TGA content in potatoes above 100 mg kg $^{-1}$ fresh weight contributes to taste deterioration (Ginzberg et al. 2009, Wszelaczyńska et al. 2020).

Edible potatoes are stored for up to 9 months, so storage conditions are important for maintaining good tuber quality. Consumable varieties are recommended to be stored at a constant temp. of 4°C and 95% RH. Not maintaining the recommended temperature, humidity or inadequate light access can promote excessive accumulation of TGAs in tubers (Chung et al. 2004, Rezaee et al. 2011, Wszelaczyńska et al. 2020).

The purpose of the study was to determine the effect of magnesium fertilization, application of a biostimulant and storage time on the TGA content and organoleptic characteristics of the edible potato variety Gala.

MATERIAL AND METHODS

The research material was the early variety of edible potato "Gala". A three-factor field experiment (2015-2017) was established using the randomized sub-block design at the Agricultural Research Station in Mochełek (Kuyavian-Pomeranian Voivodeship) belonging to the Bydgoszcz University of Science and Technology (53°13′N, 17°51′E).

The experimental factors were:

– assessment date (A) – immediately after harvest and after 6 months of storage;
– magnesium fertilization (B) – MgO doses: 30, 60, 90 kg ha^{-1};
– biostimulant application (C) –1.5, 3.0 l ha^{-1}.

Mineral magnesium was applied to the soil before potato planting in the form of 16% magnesium sulfate ($MgSO_4$) with constant NPK fertilization at doses: 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%.

The biostimulant Protifert LMW was applied three times: to plants with a height of 15 cm, immediately after flowering and 2 weeks after flowering. Biostimulant Protifert LMW is a liquid fertilizer containing a peptide of organic origin and amino acids. It is produced from natural raw materials. It is characterized by systemic translocation in the plant and rapid absorption due to its water solubility. Protifert LMW stimulates plant absorption of nutrients, increases the effectiveness of plant protection products and improves soil structure.

In each year of the field experiment, potatoes were planted with a mechanical planter in the last ten days of April. The experiment was established in plots of 33.6 m^2 with a row spacing of 0.75 x 0.35 m. 22.4 m^2 were assigned for harvesting. In each year, the preceding crop for the potato was cereal. In the autumn, manure was applied at a dose of 25 Mg ha^{-1}.

Chemical protection of plants against pests and diseases as well as agrotechnical treatments were carried out in accordance with the principles of optimal agrotechnology for potatoes. During the cultivation, the following potato protection agents were applied: herbicide – Afalon 50WP (linuron) in a dose of 2 l ha^{-1}, fungicides – Ridomil Gold MZ 67.8 WG (metalaxyl-M + mancozeb) dosed at 2 kg·ha^{-1} and Acrobat MZ 69 WG (dimetomorf + mancozeb) dosed at 2 kg ha^{-1} as well as insecticides – Mospilan 20 SP (acetamiprid) in a dose of 80 g ha^{-1} and Calypso 480SC (tiachloprid) in a dose of 0.08 l ha^{-1}.

The tubers were harvested at full maturity. Samples of 10 kg of tubers were taken from each experimental site for analytical tests immediately after harvesting and after long-term storage. The samples were placed in a controlled-atmosphere storage facility for a period of 6 months (October-March). A constant temp. of 4°C and a relative humidity of 95% were maintained throughout the storage period. The tubers were stored in two chambers (Thermolux Chłodnictwo Klimatyzacja, Raszyn, Polska) in the Institute of Food Commodities of Bydgoszcz University of Science and Technology. Each experimental storage chamber was 2 m high, 2 m wide and 3.8 m long. The tank shell material was milky-white translucent polypropylene sheets. Milk-white translucent polypropylene sheets as the tank shell material ensure such benefits as flame retardancy, moisture and light resistance, as well as providing heat isolation. In addition, in order to simulate the temperature environment and decrease heat loss, the experimental storage chamber was coated with 20 mm thick foam insulation material. The chambers were equipped with an automatic system for maintaining humidity in the storage chambers. When it fell below 95%, the system switched on and fogged the air through nozzles. The experiment was set up on a Luvisol (LV) soil, which had a fine sandy loam texture. The soil parameters are shown in Table 1. Average monthly air temperature and total rainfall in the years 2015-2017 and in the multi-year period 1996-2014 are shown in Table 2.

Throughout the 2015 growing season, with the exception of August and September, the temperature was below that for the multi-year period average. There were also small amounts of precipitation compared to the multi-year total. During the 2016 and 2017 growing seasons, air temperatures were similar to those for the multi-year period. However, during the 2016 growing season, May, August and September received less precipitation than for the multi-year period. In contrast, less precipitation in 2017occurred only in May and August.

Consumer evaluation of potato tubers was performed immediately after harvest and after 6 months of storage. The evaluation was carried out

Table 1

Soil parameters before the field experiment (average of 2015-2017)

Parameter	Amount	Abundance
pH $_{H_2O}$	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 rainfall in the years 2015-2017 and in the multi-year period 1996-2014

Month	Air temperature (C°)				Rainfall (mm)			
	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

by a permanent team of 10 people in accordance with PN-ISO 8586 (Roztropowicz et al. 1999).

The scope of organoleptic evaluation included:

– smell (scale of 4 points: 1 – neutral, 4 – foreign) according to Zimnoch--Guzowska, Flis (2006);
– taste (scale of 9 points: 9 – very good, 1 – bad) according to Wroniak (2006);
– color (scale of 6 points: 1 – white flesh, 6 points – dark yellow) according to Keutgen et al. (2014);
– darkening of tubers after cooking: after 10 min and 24 h (scale of 9 points: 9 – non-darkening, 1 – black) according to Zgórska (2013);
– darkening of raw tubers after 10 min and 4 h (scale of 9 points: 9 – non-darkening, 1 – black) according to Zgórska (2013).

To determine the TGA content, the potato material was extracted according to the Bergers (1980) method, in which the lyophilized material is dissolved in 0.5 mL of 7% (v/v) phosphoric acid and kept at -20°C until testing. To determine the total TGA content, 200 μL of the extract was added to 1 mL of 0.03% (w/v) paraformaldehyde in concentrated phosphoric acid. After color unfolding (20 min), the absorbance was tested (600 nm on Shimadzu UV-1800 Japan) and the TGA concentration was measured on the basis of α-solanine and α-chaconine (Sigma-Aldrich, St. Louis, MO, USA) standard curves.

The test results were subjected to statistical calculations. The method of variance analysis for three-factor experiments was used for statistical calculations. The Tukey's test was used to assess the significance of differences, at the level of α = 0.05. The calculations were made in the FR-ANALWAR program based on Microsoft Excel. In order to obtain a synthetic picture of the overlapping dependencies between the examined features, a simple linear correlation (Pearson) analysis was performed.

RESULTS AND DISCUSSION

Smell

The results of the post-cooking smell of the Gala variety potato tubers depending on the cultivation technology and the date of evaluation are presented in Table 3. As can be seen from the data, regardless of the factors used, the tubers of the tested variety were characterized by a neutral smell and received an average score of 1.2 points. Polish potato varieties are generally characterized by a neutral smell (Zimnoch-Guzowska, Flis 2006, Zarzecka et al. 2010, Zarzecka, Gugała 2011). Many authors (Zarzyńska, Goliszewski 2006, Styszko, Kamasa 2007, Zarzyńska, Wroniak 2007, Pyryt, Kolenda 2009) state that potato tuber smell is a stable trait, but can be affected by genetic conditions. On the other hand, according to Ciećko et al. (2005) the smell of tubers after cooking depends mainly on the esters, alcohols, aldehydes, pyrazines and volatile sulfur compounds contained in them.

In the conducted study, magnesium fertilization and application of a biostimulant during the growing season significantly affected the tuber flesh smell both immediately after harvest and after storage. Each of the applied doses of magnesium caused the tuber flesh smell to change to a more noticeable one compared to the control object. The most noticeable smell was obtained after the application of a dose of 60 kg MgO ha^{-1} both after harvest and after storage. The opposite view is expressed by Rogozińska et al. (2004) in their study, in which increasing doses of magnesium fertilization increased the concentration of this element in the tubers, which contributes to improving their smell. On the other hand, application of the biostimulant

Table 3

Sensory evaluation of cooked potato tubers of the Gala variety depending on the cultivation technology and evaluation date (average of 2015-2017)

MgO fertilization doses (B) (kg ha^{-1})	Potato tuber evaluation date (A)					
	directly after harvest			after storage		
	smell	taste	color	smell	taste	color
Without biostimulant application, control (C)						
0	1.0	7.0	4.6	1.0	6.9	4.4
30	1.4	7.0	4.7	1.4	8.0	4.5
60	2.0	8.0	5.1	2.0	7.4	4.8
90	1.4	7.4	5.0	1.4	7.1	4.8
Average	1.4	7.3	4.8	1.4	7.3	4.6
Biostimulant application – 1.5 l ha^{-1} (C)						
0	1.0	7.0	4.5	1.0	7.3	4.5
30	1.0	7.5	4.5	1.0	7.5	4.5
60	1.0	8.3	5.0	1.0	8.0	4.8
90	1.0	7.3	5.0	1.0	8.3	5.0
Average	1.0	7.5	4.8	1.0	7.8	4.7
Biostimulant application – 3.0 l ha^{-1} (C)						
0	1.0	7.8	4.3	1.0	7.0	4.5
30	1.0	6.5	4.8	1.0	8.0	4.5
60	1.0	7.0	5.0	1.0	7.3	4.6
90	1.0	7.5	5.3	1.3	7.3	4.8
Average	1.0	7.2	4.8	1.1	7.4	4.6
Average						
0	1.0	7.3	4.4	1.0	7.0	4.5
30	1.1	7.0	4.7	1.1	7.8	4.5
60	1.3	7.8	5.0	1.3	7.5	4.7
90	1.1	7.4	5.1	1.2	7.6	4.8
Average	1.2	7.3	4.8	1.2	7.5	4.6

$NIR_{0.05}$ (Tukey's test)

Smell		
A – ns	B – 0.16	C – 0.13
B/A – ns	A/B – ns	B/C – 0.27
A/C – ns	C/B – 0.27	B/C – 0.27
Taste		
A – ns	B – 0.39	C – 0.13
B/A – 0.55	A/B – 0.54	B/C – ns
A/C – ns	C/B – 0.26	B/C – 0.44
Color		
A – ns	B – 0.19	C – ns
B/A – ns	A/B – ns	B/C – 0.13
A/C – 0.20	C/B – 0.18	B/C – 0.24

ns – non-significant

in any amount contributed to the improvement of smell. The results of organoleptic evaluations indicate that the smell of cooked tubers did not change after long-term storage. In contrast, according to Krochmal-Marczak et al. (2016), long-term (8 months) storage worsened cooked tuber flesh smell.

Taste

The results for taste scoring are shown in Table 3. Of all the characteristics included in consumer evaluation, taste and aroma impressions are the most subjective. Wszelaczyńska et al. (2013) state that organoleptic evaluation should include palatability, which is defined as the set of taste and smell sensations experienced during consumption. Zarzecka et al. (2010) and Zarzecka, Gugała (2011) report that Polish varieties are mostly characterized by very good palatability. Our results confirm this as the studied variety was characterized by good palatability. The analysis of variance showed that the cultivation technology had a significant effect on the taste of the of the Gala variety tubers tested after cooking. Both the application of different magnesium fertilization and biostimulant doses improved the taste of the tubers after cooking. Increasing magnesium fertilization resulted in some improvement in the taste of cooked tubers compared to the control, and the best result in this regard was achieved by the magnesium dose of 60 kg MgO ha^{-1}. Flis et al. (2012) report that taste is influenced by the minerals contained in the tubers. Application of the biostimulant at 1.5 l ha^{-1} significantly improved tuber flavor compared to the control. Increasing the application dose to 3 l ha^{-1} had no effect on the taste of the tested variety. A similar opinion is held by Płaza (2010), who claims that the palatability of potato tubers changes significantly under the influence of environmental conditions. Additionally, Grudzińska et al. (2016) proved significant influence of the cultivation technology on taste as an organoleptic evaluation discriminator. Our study did not confirm a significant effect of TGA on potato flavor, as there was no significant correlation between the TGA content and flavor (Tables 4 and 5). However, it should be noted that the content of TGA in our study was at a low level and many authors (Ginzberg et al. 2009, Wszelaczyńska et al. 2020) suggest the taste deteriorates after exceeding 100 mg kg^{-1}. Long-term storage did not change the taste of tubers of the studied variety. Krochmal-Marczak et al. (2016) reported opposite findings in their study, where eight-month storage caused deterioration of the taste of the three edible varieties tested: Americana, Denar, and Lord.

Color

It is known that the color of potato flesh is a varietal feature. It can be white, creamy or yellow with a range of intermediate shades. Its determination serves primarily to satisfy consumer tastes (Gugała, Zarzecka 2007, Rytel et al. 2008, Pyryt, Kolenda 2009, Płaza 2010, Zarzecka et al. 2010,

Table 4

Linear correlation analysis (Pearson) of the studied characteristics of the Gala potato variety directly after harvest

Specification	Smell	Taste	Color	DR 10 min	DR 4 h	DC 10 min	DC 24 h
Taste	0.384						
Color	0.428	0,517					
DR 10 min	ns	ns	0.356				
DR 4 h	ns	ns	0.370	ns			
DC 10 min	ns	ns	ns	ns	ns		
DC 24 h	-0.460	ns	ns	ns	ns	0,646	
TGA	0.390	ns	0.422	ns	ns	ns	-0,336

Indicates that the correlation is significant at the 0.05 probability level >0.334.
ns – non-significant, DR 10 min – darkening of raw potatoes after 10 min, DR 4 h – darkening of raw potatoes after 4 h, DC 10 min – darkening of cooked potatoes after 10 min, DC 24 h – darkening of cooked potatoes after 24 h, TGA – total glycoalkaloids content

Table 5

Linear correlation analysis (Pearson) of the studied characteristics of the Gala potato variety after 6 months of storage

Specification	Smell	Taste	Color	DR 10 min	DR 4 h	DC 10 min	DC 24 h
Taste	ns						
Color	ns	ns					
DR 10 min	-0.430	ns	ns				
DR 4 h	ns	ns	ns	ns			
DC 10 min	ns	ns	ns	ns	ns		
DC 24 h	ns	ns	ns	ns	ns	0.512	
TGA	ns	ns	0.433	ns	ns	-0.399	-0.430

indicates that the correlation is significant at the 0.05 probability level >0.334.
ns – non-significant, DR 10 min – darkening of raw potatoes after 10 min, DR 4 h – darkening of raw potatoes after 4 h, DC 10 min – darkening of cooked potatoes after 10 min, DC 24 h – darkening of cooked potatoes after 24 h, TGA – total glycoalkaloids content

Zarzecka, Gugala 2011). This feature is therefore a critical physical property for commercial classification and purchasing decisions. The color parameter is also the primary function of quantifying freshness, which it is particularly important for raw potatoes intended for direct consumption (Kidoń, Czapski 2010, Wszelaczyńska et al. 2013, Keutgen et al. 2014). Edible varieties of potatoes registered in Poland are distinguished by yellow and light yellow color (Zarzecka, Gugała 2011, Wszelaczyńska et al. 2013), which is confirmed by the conducted research. It was shown that the agrotechnical factor applied in the experiment, in the form of magnesium fertilization, significantly modified the flesh color of the studied tubers (Table 3). Gugała, Zarzecka (2007) report that the application of various factors during the growing season can cause a change in the flesh color. On the other hand, according to Hamouz et al. (2006), the flesh color depends on the organic acid content and, according to Zimnoch-Guzowska and Flis (2006) and Tilahun et al. (2020), on the concentration of carotenoids, anthocyanins and solanine. Some authors (Tilahun et al. 2020) showed a significant correlation between the raw tuber's flesh color and tuber's solanine content. In our research, immediately after harvest and following long-term storage, correlation coefficients also indicate a significant relationship between the color and TGA content, at r = 0.422 and r = 0.433, respectively (Tables 4 and 5). In the study, each of the applied doses of magnesium during the growing season resulted in a change in the hue of the flesh color of the Gala variety to more yellow than in the control. Similar results were obtained by Rogozińska et al. (2004) in an experiment with the edible variety Mila. The authors showed that the application of magnesium to plants during the growing season included a change in the intensity of flesh coloration of the studied variety. No significant effect of long-term storage on tuber color change was observed. A different opinion is declared by Płaza et al. (2010), Krzysztofik and Skonieczny (2010), Pobereżny and Wszelaczyńska (2011), Wszelaczyńska and Pobereżny (2011), Wszelaczyńska et al. (2013), who maintain that long-term potato storage contributes to changes in the intensity of potato tuber flesh coloration.

Tuber darkening

The results concerning the propensity of the flesh of the Gala variety raw tubers to darken evaluated both 10 min and 4 h after cutting are shown in Table 6. It should be emphasized that the studied variety is genetically characterized by low propensity to darkening (Ciećko et al. 2005, Zgórska et al. 2006). Regardless of the cultivation technology used, immediately after harvest, the propensity of raw flesh to darken after 10 min was assessed at 8.7 points, and after 4 h – at 8.0 points. The applied magnesium fertilization and spraying with the biostimulant during the growing season significantly reduced the tendency for flesh to darken after 10 minutes. In this regard, doses of 60 kg MgO ha and 1.5 l ha were the most effective, respectively. No such results were obtained regarding the evaluation of raw tubers after 4 hours. A similar view is expressed by Wszelaczyńska (2004), Zgórska et al. (2006) and Keutgen et al. (2014), who claim that the propensity of the flesh of raw tubers to darken depends mainly on agrotechnical factors. Of a different opinion are Gugała and Zarzecka (2007), who proved that the method of potato cultivation and care had no effect on the darkening of raw tuber flesh. In addition, our study showed a significant but low correlation (P<0.05) between the darkening process of raw tubers at 10 min and 4 h after cutting and color: r = 0.356 and 0.370, respectively (Table 4). This relationship indicates that flesh color is affected by the course of non-enzymatic

Table 6

Evaluation of darkening after 10 min and 4 h of raw potato tubers of the Gala variety depending on the cultivation technology and evaluation date (average of 2015-2017)

MgO fertilization doses (B) (kg ha^{-1})	Potato tuber evaluation date (A)			
	directly after harvest		after storage	
	after 10 min	after 4 h	after 10 min	after 4 h
Without biostimulant application, control (C)				
0	8.8	7.9	8.8	7.2
30	8.6	8.1	8.6	7.7
60	8.9	8.4	8.8	7.6
90	8.6	8.1	8.7	7.7
Average	8.7	8.1	8.7	7.6
Biostimulant application – 1.5 l ha^{-1} (C)				
0	8.9	7.9	8.8	7.7
30	8.5	8.0	8.9	7.2
60	8.9	8.0	9.0	7.5
90	8.8	8.0	8.6	7.2
Average	8.8	8.0	8.8	7.4
Biostimulant application – 3.0 l ha^{-1} (C)				
0	8.6	8.2	8.4	7.2
30	8.8	7.8	8.3	7.3
60	8.9	7.9	8.6	7.6
90	8.5	8.0	8.2	7.6
Average	8.7	8.0	8.4	7.4
Average				
0	8.8	8.0	8.7	7.4
30	8.6	8.0	8.6	7.4
60	8.9	8.1	8.8	7.6
90	8.6	8.0	8.5	7.5
Average	8.7	8.0	8.6	7.5

$NIR_{0.05}$ (Tukey's test)

Darkening after 10 min

A – 0.12	B – 0.31	C – 0.10
B/A – ns	A/B – ns	B/C – ns
A/C – ns	C/B – 0.20	B/C – 0.35

Darkening after 4 h

A – 0.42	B – ns	C – ns
B/A – ns	A/B – ns	B/C – ns
A/C – ns	C/B – ns	B/C – ns

ns – non-significant

darkening processes in tubers (Keutgen et al. 2014). According to Gugała and Zarzecka (2007), enzymatic darkening of flesh depends on edaphic conditions. Color, on the other hand, depends not only on edaphic conditions but also on agrotechnical conditions.

Statistical analysis showed a significant effect of magnesium fertilization and the application of the biostimulant on the darkening of the flesh of cooked potato tubers after 10 min and 24 h (Table 7). The only exception is the effect of magnesium fertilization on the degree of darkening of cooked flesh after 24 h, as no significant effect was shown. The degree of darkening of the flesh of cooked potato tubers on objects fertilized with magnesium at a dose of 30 kg ha and after the application of the biostimulant at 1.5 l ha was the brightest. On the other hand, the highest intensity of gray coloration of cooked flesh was recorded in tubers harvested from the control object, both after 10 min and after 24 h. The above correlation is not confirmed by Ceglarek et al. (1998), who showed that potatoes grown in soil treated with mineral fertilizers were characterized by a higher intensity of gray color than potatoes in soil supplied manure or green manures. The intensity of darkening depends on the content of phenolic compounds and is largely a genetic trait. The amount of these compounds depends on edaphic conditions, including soil type, meteorological conditions of the growing season, fertilization, the degree of tuber maturity, etc. (Ding et al. 2002). The darkening of the cooked flesh of potato tubers was also differentiated by the timing of the tests. Potatoes evaluated immediately after harvesting were characterized by a lower degree of darkening of the cooked flesh after 10 minutes and 24 hours than tubers evaluated after long-term storage. According to many authors (Keutgen et al. 2014, Wszelaczyńska et al. 2016), long-term storage always deteriorates the quality of tubers in terms of their tendency to flesh darkening. This is often caused by the inability to maintain stable conditions during storage (Pobereżny, Wszelaczyńska 2011, Wszelaczyńska, Pobereżny 2011). This research confirmed the negative effect of long-term storage on the tendency for the flesh of tubers to darken. As a result of storage, there was an increase in the darkening of both raw and cooked tuber flesh. Increased propensity for enzymatic and non-enzymatic darkening of flesh under the influence of storage was also reported by Wszelaczyńska (2004), Keutgen et al. (2014) and Wszelaczyńska et al. (2017). The authors conducted a study on other edible varieties, which, same as in our experiment, showed an increase in the propensity of the flesh for darkening. It should be noted, however, that the change in the consumption value of the parameter was small, as the varieties tested in the above studies still belonged to the group of potatoes with a very low propensity to darkening.

TGA content

Regardless of the factors used, the TGA content of the tubers of the Gala variety was at low, both after harvest 35.1 and after storage 37.9 mg kg^{-1} fresh weight (Table 8). Gugała et al. (2016), in their research on three edible

Table 7

Evaluation of darkening after 10 min and 24 h of cooked potato tubers of the Gala variety depending on the cultivation technology and evaluation date (average of 2015-2017)

MgO fertilization doses (B) (kg ha^{-1})	Potato tuber evaluation date (A)			
	directly after harvest		after storage	
	after 10 min	after 24 h	after 10 min	after 24 h
Without biostimulant application, control (C)				
0	8.7	8.4	8.6	8.3
30	8.8	8.6	8.7	8.4
60	8.7	8.3	8.4	8.2
90	8.6	8.3	8.3	8.1
Average	8.7	8.4	8.5	8.2
Biostimulant application – 1.5 l ha^{-1} (C)				
0	8.9	8.6	8.9	8.5
30	9.0	9.0	9.0	8.5
60	8.8	8.5	8.3	8.3
90	8.8	8.4	8.5	8.3
Average	8.9	8.6	8.7	8.4
Biostimulant application – 3.0 l ha^{-1} (C)				
0	8.5	8.1	8.3	8.0
30	8.6	8.3	8.5	8.1
60	8.6	8.0	8.5	7.7
90	8.5	8.1	8.1	8.0
Average	8.6	8.1	8.3	7.9
Average				
0	8.7	8.4	8.6	8.3
30	8.8	8.6	8.7	8.3
60	8.7	8.3	8.4	8.0
90	8.6	8.3	8.3	8.1
Average	8.7	8.4	8.5	8.2

$NIR_{0.05}$ (Tukey's test)

Darkening after 10 min

A – 0.11	B – 0.23	C – 0.13
B/A – ns	A/B – ns	B/C – ns
A/C – ns	C/B – ns	B/C – ns

Darkening after 24 h

A – 0.08	B – ns	C – 0.13
B/A – ns	A/B – ns	B/C – ns
A/C – ns	C/B – ns	B/C – ns

ns – non-significant

Table 8

Total glycoalkaloid content in potato tubers of the Gala variety depending on the cultivation technology and evaluation date (mg kg^{-1} f. m.), average of 2015-2017

MgO fertilization doses B (kg ha^{-1})	Potato tuber evaluation date (A)	
	directly after harvest	after storage
Without biostimulant application, control (C)		
0	30,9	33,6
30	33,2	36,6
60	34,3	38,1
90	35,5	40,0
Average	33,5	37,1
Biostimulant application – 1.5 l ha^{-1} (C)		
0	32,9	35,6
30	34,3	36,9
60	35,2	37,6
90	36,6	38,4
Average	34,8	37,1
Biostimulant application – 3.0 l ha^{-1} (C)		
0	35,3	37,4
30	36,2	39,1
60	37,5	40,2
90	38,7	41,1
Average	37,0	39,5
Average		
0	33,0	35,5
30	34,6	37,5
60	35,7	38,6
90	37,0	39,9
Average	35,1	37,9
$NIR_{0.05}$ (Tukey's test)		
A – 2.55	B – 1.27	C – 0.77
B/A – ns	A/B – ns	B/C – ns
A/C – ns	C/B – ns	B/C – ns

ns – non-significant

potato varieties, obtained higher TGA content. The TGA content averaged 91.14 mg kg^{-1} fresh weight of the Honorata variety tubers up to 92.31 for the Bartek variety tubers. Many authors (Friedman 2006, Wroniak 2006, Zarzyńska 2013, Wszelaczyńska 2020) indicate that the average TGA content of tubers for consumption is between 20-100 mg kg^{-1} fresh weight. According to Şengül et al. (2004) and Zarzyńska (2013), edible potato tubers should have a TGA content of less than 50 mg kg $^{-1}$ FW. In our study, the application of magnesium fertilization as well as that of the biostimulant increased the TGA content in tubers after harvest. Each dose of magnesium increased the TGA content, and the highest content was in tubers from the object fertilized with 90 kg ha^{-1}. Wszelaczyńska et al. (2020) applied magnesium in doses ranging from 20 to 100 kg ha^{-1} and showed that each increase in the Mg dose raised the TGA content of tubers after harvest. They obtained the highest TGA content following the application of using 100 kg. The supply of magnesium during the growing season of plants can accelerate the intensity of photosynthesis, as a result of which the content of nitrogen compounds in tubers increases (Cakmak, Kirkby 2008, Wszelaczyńska 2020). A similar effect was obtained after the biostimulant application, as the highest TGA content was observed in tubers of plants treated with the highest dose of the biostimulant, i.e. 3.0 l ha^{-1}, during the growing season. Gugała et al. (2016), in an experiment with biostimulants, also obtained a significant increase in the content of TGA in tubers. However, it should be noted that the highest increase in TGA was on the plots where only herbicides were applied, without the addition of biostimulants. According to Bejarano et al. (2000), the TGA content in tubers increases due to stress conditions during the growing season so biostimulants that increase plant resistance to stress conditions may contribute to lower TGA (Du Jardina 2015, Hara 2019). Long-term storage (6 months) resulted in an average 7.5% increase in the TGA content in the tubers studied. Similar results were obtained by Zgórska, Sowa-Niedziałkowska (2005) and by Wszelaczyńska et al. (2020) in their studies, where the TGA content increased significantly after storage. Wszelaczyńska et al. (2020) obtained a significant increase in TGA both after three months (by 22%) and after six months (by 38%). In contrast, in the Zgórska, Sowa-Niedziałkowska (2005) study, a significant increase was found only after a longer storage period of as many as eight months (an increase of 35% at a storage temp. of 4°C and 70% at 8°C).

CONCLUSION

The study showed that the application of magnesium during the potato growing season caused a change in the intensity of tuber flesh color to a more yellow color, and increased the content of TGA. The greatest effect in this regard was produced by the dose of 90 kg MgO ha^{-1}. In addition, the application of magnesium reduced the darkening processes of both raw and cooked tubers. The best results in this regard were obtained after the application of magnesium in soil at 30 and 60 kg ha^{-1}. The application of the biostimulant had a positive effect on the distinguishing features of the consumption value: taste and smell. The best taste and neutral smell were obtained by potato tubers from objects where the biostimulant was applied at a dose of 1.5 l ha^{-1}. Application of the biostimulant increased the TGA content in tubers. Long-term storage generally deteriorated the quality of potatoes of the Gala variety in terms of all tested organoleptic characteristics and increased the TGA content.

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