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RELATIONSHIP BETWEEN THE VITAMIN C AND NITRATE CONTENT IN POTATO TUBERS DEPENDING ON THE MATURITY GROUPS OF CULTIVARS*

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Abstract

The purpose of the research, carried out in 2012-2020, was to determine the impact of maturity of different groups of cultivars and weather conditions during the growing season on the vitamin C and nitrate content in potato tubers, as well as to study the relationship between these components. The research was carried out in light soil, on 39 edible cultivars divided into 3 maturity groups: very early (6), early (12) and medium-early (21). Each cultivar was grown in a 3-year cycle. Straw and white mustard catch crop were used as organic fertilizers. Mineral fertilization was applied, with a dose of 100 kg N ha^{-1}, 26.2 kg P ha^{-1}, 99.6 kg K ha^{-1}. The content of vitamin C was determined using the Tillman's method. Nitrates were determined according to the colorimetric method based on the Griess test. The assessment of weather conditions during the research period was done according to the Selyaninov´s hydrothermal coefficient. Significant differences were observed in the vitamin C and nitrate content in tubers, and the relationship between these components and the maturity groups of cultivars as well as weather conditions during the research period. The highest levels of vitamin C and nitrates were found in tubers from the very early maturity group, and the lowest – from the medium-early maturity group. The weather conditions during the research period had a greater influence on the vitamin C and nitrate content in tubers than the maturity group of cultivars. During wet years, the ratio of vitamin C to nitrates was significantly higher. A more favourable ratio of vitamin C to nitrates was observed in cultivars from the early and mid-early maturity groups than from the very early group.

Keywords: nitrates, vitamin C, growing season, tubers, potato.

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INTRODUCTION

Potato tubers, owing to their high consumption, are a significant source of vitamin C, which consists of ascorbic acid and dehydroascorbic acid. Depending on the influence of environmental factors related to the weather conditions, genotype, and other factors, the content of vitamin C in tubers may vary greatly, ranging from 50 to 300 mg^{-1} kg of fresh weight (Gąsiorowska, Zarzecka 2002, Kraska 2002, Leszczyński 2000, Zimnoch-Guzowska, Flis 2006). One of the principal effects of vitamin C presence in potato tubers is the vitamin's antagonistic effect on nitrates. Nitrates in turn are a natural component of potato tubers, due to the incorporation of nitrogen into amino acids and protein formation. The influence of certain agrotechnical factors during the growing period of potato plants may lead to nitrate excess in tubers, which can result in the formation of nitrosamines, substances with mutagenic and carcinogenic effects, in the human body (Hippe 1996, Mensinga et al. 2003). Ascorbic acid reduces nitrite to nitric oxide, thus eliminating nitrosation precursors such as nitrites (Massey et al. 1982, Reyes et al. 2005). Hence, it is not only the content of vitamin C, but also its ratio to the nitrate content that indicate a specific nutritional value of tubers (Cieślik 1994, Lachman et al. 1997, Mazurczyk, Lis 2004). It has been proven that higher vitamin C content in food reduces the negative impact of nitrates on the body (Wawrzyniak et al. 1997, Nara et al. 2006). It should be noted that the content of these important nutrients in potato tubers is largely dependent on genetic predispositions and may be subject to significant fluctuations due to the influence of abiotic factors during the growing season of potato plants and post-harvest (Rogozińska et al. 2005, Kołodziejczyk 2013, Wszelaczyńska et al. 2020*a*).

Hence, the purpose of the research was to assess the impact of potato genotypes belonging to different maturity groups and the weather conditions during the research period on the vitamin C content in relation to the nitrate content in tubers.

MATERIAL AND METHODS

In 2012-2020, a trial was carried out in the Jadwisin Branch (52°45′N, 21°63′E) of the Plant Breeding and Acclimatization Institute of the National Research Institute, on the content and relationship between vitamin C and nitrates in potato tubers belonging to different maturity groups. Controlled field and laboratory experiments were conducted. Thirty-nine edible cultivars from three maturity groups were included in the study: very early: Flaming, Impresja, Ingrid, Riviera, Tonacja, Viviana (6), early: Altesse, Bohun, Carrera, Cyprian, Gwiazda, Hubal, Ignacy, Lady Rosetta, Lawenda, Madeleine, Magnolia, Michalina (12), and medium-early: Aldona, Ametyst, Bogatka, Bojar, Bursztyn, Etiuda, Gawin, Honorata, Igor, Jurata, Jurek, Jutrzenka, Laskara, Lech, Legenda, Malaga, Mazur, Oberon, Otolia, Stasia, Tetyda (21). Each cultivar was grown in a 3-year cycle. The experiments were carried out using a random blocks method with 3 replications. The plot area was 7.425 m^2, with 30 plants per plot. The row spacing in the plot was 0.75 m and the distance between the plants in a row was 0.33 m.

The research was carried out on podzolic soil with the particle size composition of light, loamy sand, determined to belong to class V soil valuation (WRB 2014). During the research period, the soil was acidic, with high assimilable phosphorus content, medium potassium, and low to medium magnesium content (Table 1). Based on the soil analysis, it was determined that the organic carbon content was low in the years 2013, 2014, 2015, and 2020, and moderate in the remaining years.

Table 1

Soil chemical properties of the field before planting

Year	C organic ($g\ kg^{-1}$)	pH in KCl	Content in the soil ($mg\ kg^{-1}$)#		
			P	K	Mg
2012	6.2	5.3	85	107	49
2013	5.5	5.5	87	124	48
2014	5.0	5.3	77	120	34
2015	5.0	5.0	83	108	35
2016	6.8	5.4	89	112	32
2017	8.4	5.0	88	122	22
2018	8.8	5.4	79	104	26
2019	6.6	5.2	75	99	22
2020	5.3	5.0	85	107	27

available forms

In terms of the weather conditions, the respective years of the research period showed significant variations. The highest rainfall during the growing season was recorded in 2013. The total rainfall for the entire growing season in 2013 was 143.3 mm higher than the multiannual one. On the other hand, the air temperature in 2013 was moderate and close to the multiannual average. Rainfall greater than the multiannual total was also recorded in 2012, 2016, 2017, and 2020. The rainfall excess throughout the growing season ranged from 31.5 mm in 2016 to 57.6 mm in 2012. 2012, in turn, was the coolest year. The air temperature for the entire growing season in 2012 was 0.7°C lower than the multiannual average. The remaining years of the research period demonstrated a shortage of precipitation during the growing season of potato plants. The precipitation deficit throughout the growing season ranged from 161.5 mm in 2015 to 65.2 mm in 2014. In general, during the years of precipitation deficit, the recorded air temperature was higher than the multiannual average. The highest air temperature, exceeding the multiannual average by 3.5°C, was recorded in 2018. Based on the Selyaninov´s hydrothermal coefficient (K), defined as the average values for given years, it was noted that the years 2015, 2018, and 2019 were dry (K coefficient value of <1), 2012, 2014, 2016, 2017, and 2020 were wet, while 2013 was classified as very wet (Table 2).

The organic fertilisation in the study comprised cut winter triticale straw, incorporated into the soil in an amount of 5 t ha^{-1}. In autumn, the green mass of white mustard stubble intercrop in an amount of 15-16 t ha^{-1} was ploughed into soil. Mineral fertilisation with phosphorus and potassium was carried out in early spring, in doses of 26.2 kg P ha^{-1} (enriched superphosphate – 17.4% P) and 99.6 kg K ha^{-1} (potassium salt – 49.8% K). Mineral nitrogen was applied in a dose of 100 kg N ha^{-1} (nitro-chalk – 27% N), in spring before planting tubers. Tubers were planted in the third ten days of April and harvested after tuber maturity (from the first ten days of September when potatoes from the very early and early cultivars were picked, to the last ten days of September to collect potatoes from the mid-early group).

Agrotechnical treatments were carried out in accordance with the principles of proper agronomy. Treatments against weeds, diseases, and pests were carried out in accordance with the principles of integrated protection. Weed control was carried out mechanically (2 treatments applied before the emergence of potato plants) and chemically (herbicide applied twice). Immediately before the emergence of potato plants, the following chemicals were applied: Afalon 50 WP (2 kg ha^{-1}) in 2012, Linuron 50 WP (2 kg ha^{-1}) in 2013-2017, and Proman 500 SC (4 l ha^{-1}) in 2018-2020. Each year before the row closure, Titus 25 WG (60 g ha^{-1}) + Trend was used. After some early stage symptoms of a fungal disease had been observed on potato plants, the following substances were used during the research period: Ekonom Duo 72 WP (2.5 kg ha^{-1}), Ridomil Gold MZ Pepite 67.8 WG (2 kg ha^{-1}), Infinito 687.5 SC (1.5 l ha^{-1}), Revus 250 SC (0.6 l ha^{-1}), Pyton Consento 450 SC (2 l ha^{-1}), Cabrio Duo (0.5 l ha^{-1}), Banjo 500 SC (0.4 l ha^{-1}), Altima 500 SC (0.4 l ha^{-1}), Amistar 250 SC (0.5 l ha^{-1}), Acrobat MZ69WG (2 kg ha^{-1}). Colorado potato beetle was controlled when the damage threshold was exceeded and the following substances were used during the research period: Actara 25 WG (70 g ha^{-1}), Apacz 50 WG (0.04 kg ha^{-1}), Calypso 480 SC (0.1 l ha^{-1}), Decis 2.5 EC (0.2 l ha^{-1}), Mospilan 20 SP (0.08 kg ha^{-1}), Proteus 110 OD (0.3 l ha^{-1}), Spin Tor 240 SC (0.1 l ha^{-1}).

During the harvest, a tuber sample weighing 5 kg was taken from each plot for analysis. Prior to chemical analysis, the samples were washed; the tubers which were damaged, green-coloured, or had a diameter of less than 35 mm were discarded. Within 2-3 weeks after the harvest, the content determination was carried out. Vitamin C content was determined as the sum of L-ascorbic acid and dehydroascorbic acid using the Tillman's method,

Table 2

Weather conditions in the research years (Meteorological station in Jadwisin)

Years	Months						Sum/ Mean
	April	May	June	July	Aug	Sept	
Sum of rainfalls (mm)							
2012	54.3	52.4	96.6	92.2	87.2	26.9	409.6
2013	51.1	130.0	105.4	17.1	97.7	94.0	495.3
2014	61.1	41.3	69.8	23.5	79.2	11.9	286,8
2015	27.8	39.5	15.4	62.6	8.6	36.6	190.5
2016	31.4	92.2	85.4	103.6	61.4	9.5	383.5
2017	8.9	10.1	107.5	78.8	57.0	140.8	407.1
2018	21.7	43.4	41.0	75.2	60.6	30.9	272.8
2019	1.7	76.6	6.9	33.4	37.0	60.8	216.4
2020	5.6	65.3	113.8	40.4	120.7	51.8	397.6
1967-2011	37.0	57.0	75.0	76.0	61.0	48.0	352.0
Mean air temperature (°C)							
2012	7.9	13.9	15.6	15.2	17.4	12.8	13.8
2013	6.3	15.7	17.2	18.7	18.2	10.3	14.4
2014	10.3	14.1	15.8	21.5	18.2	14.8	15.8
2015	8.3	12.9	17.5	19.6	22.5	15.1	16.0
2016	9.3	15.3	18.7	19.6	18.4	15.7	16.2
2017	7.3	14.1	18.1	18.4	19.4	13.8	15.2
2018	13.2	17.6	19.1	21.2	20.8	15.8	18.0
2019	10.2	13.4	22.7	18.8	20.8	14.7	16.8
2020	8.8	11.6	18.7	19.0	20.1	15.5	15.6
1967-2011	7.9	13.7	16.6	18.5	17.9	13.2	14.5
Selyaninov's hydrothermal coefficients (K)[#]							
2012	2.28	1.21	2.06	1.95	1.61	0.67	1.63
2013	2.68	2.95	2.04	0.29	1.73	2.86	2.09
2014	1.98	0.92	1.47	0.35	1.40	0.26	1.06
2015	1.12	0.99	0.29	1.02	0.12	0.80	0.72
2016	1.12	1.94	1.52	1.70	1.07	0.20	1.26
2017	0.40	0.23	1.98	1.38	0.95	3.39	1.39
2018	0.54	0.79	0.71	1.14	0.93	0.65	0.79
2019	0.06	1.85	0.10	0.57	0.57	1.38	0.76
2020	0.21	1.81	2.03	0.68	1.93	1.11	1.30

[#] Coefficient value (Bac et al. 1998): K< 0.50 strong drought, K – 0.51-0.99 drought, K – 1.00-2.00 wet, K>2.00 very humid.

by titration with a 2.6-dichlorophenolindophenol solution (Rutkowska 1981). Nitrates were determined according to the colorimetric method based on the Griess test (Zalewski 1971). In order to convert nitrates from the NO_3 to the $NaNO_3$ form, a 1.37 factor was applied.

The results of the experiments were processed using analysis of variance (ANOVA) in relation to the maturity groups of the cultivars and the years of the research period, as well as linear regression in determining the relationship between the content of vitamin C and nitrates in tubers. The calculations were performed using the Statistica 13.3. analytics system. The means comparison analysis was carried out with the Tukey's test at p=0.05.

RESULTS AND DISCUSSION

The research showed a highly significant variability of vitamin C, nitrates, and the relationship between them depending on the maturity group of a cultivar, weather conditions, and the relationship between these factors (Table 3). It was determined that vitamin C content in tubers increased

Table 3

The source of variation for factors and features

Factor	Feature		
	vitamine C	nitrates ($NaNO_3$)	vitamine C/nitrates
F maturity (1)	1059	10071.1	998.71
F years (2)	5551	15741.8	2810.46
F (1x2)	2535	1111.7	281.41
P maturity (1)	0.0001	0.0001	0.0001
P years (2)	0.0001	0.0001	0.0001
P (1x2)	0.0001	0.0001	0.0001
Significant (1)	**	**	**
Significant (2)	**	**	**
Significant (1x2)	**	**	**

** very significant at p=0.05

along with the extension of the growing season of cultivars. The highest vitamin C content was observed in tubers from the very early cultivar group – 210.55 mg kg^{-1}, and the lowest for medium-early cultivars – 201.06 mg kg^{-1} (Table 4). In comparison with the abovementioned results, previous studies have shown a lower vitamin C content in tubers and a more significant difference between the very early and early cultivar group and the medium--early cultivar group (Trawczyński, Wierzbicka 2012). Such an outcome is probably linked to the fact that during the present study, a greater number of wet years was recorded, which positively influenced the vitamin C content and stabilized its level in tubers. A greater variability of vitamin C due to the influence of genetic factors has also been observed in previous studies (Hamouz et al. 2007, Wichrowska, Pobereżny 2008, Hamouz et al. 2009, Barbaś, Sawicka 2015). A relatively lower vitamin C content was recorded during the years when droughts of varying severity occurred in June, July or August, i.e. the crucial growing season months (K value <1). In the wet years (K value>1) during the period from June to August (2012 and 2017), the conditions were favourable for the accumulation of vitamin C in tubers (Table 4). However, in the studies by Gugała et al. (2019), lower

Table 4

Content of vitamin C content in potato tubers depending on the maturity groups. Years 2012-2020

Years	Group of maturity			Mean
	very early	early	mid early	
2012	251.44*a*	248.38*b*	163.38*c*	221.07*b*
2013	211.55*a*	198.38*b*	197.44*b*	202.46*e*
2014	176.00*b*	169.63*c*	197.38*a*	181.00*f*
2015	205.00*a*	202.00*a*	199.55*a*	202.18*e*
2016	186.00*c*	201.00*b*	219.00*a*	202.00*e*
2017	237.00*a*	236.53*a*	237.38*a*	236.97*a*
2018	218.44*a*	220.44*a*	207.50*b*	215.46*c*
2019	203.55*b*	208.00*a*	208.38*a*	206.64*d*
2020	159.44*c*	206.00*a*	179.55*b*	181.66*f*
Mean	210.55*a*	204.55*b*	201.06*c*	

Means with the same letter do not differ significantly.

levels of vitamin C were observed in tubers exposed to increased rainfall. A greater variability of vitamin C content in tubers was observed among the research years, from 181.0 in 2014 to 236.97 mg kg^{-1} of fresh weight in 2017, than in relation to the maturity group of a cultivar. This indicated a more significant influence of weather conditions during the research period than of the maturity group on the vitamin C content in tubers. In the studies by Hamouz et al. (2009), the increase of vitamin C content in tubers was associated with an increase in air temperature.

Moreover, significant differences of the nitrate content in tubers were observed among all analysed maturity groups of cultivars. The nitrate content was the highest in the tubers from the very early cultivar group and the lowest in the medium early group. In general, studies seem to confirm the convergence between the decreasing level of nitrate content and the extension of the growing season of cultivars (Frydecka-Mazurczyk, Zgórska

2000). In the studies by Mazurczyk and Lis (2000), the nitrate content in tubers from the very early and early cultivar group was 224 mg kg^{-1}, in the medium-early cultivar group it was 108 mg kg^{-1}, while in the medium--late and late cultivar group it was only 44 mg kg^{-1} fresh weight. Similarly to the vitamin C content, a greater variability of the nitrate content (from 40.38 to 176.81 mg kg^{-1} of fresh tuber weight) was recorded in relation to the weather conditions than to the maturity groups of cultivars (from 86.33 to 127.72 mg kg^{-1} of fresh tuber weight) – Table 5. During dry years,

Table 5

Content of nitrates ($NaNO_3$) content in potato tubers depending on the maturityy groups. Years 2012-2020

Years	Group of maturity			Mean
	very early	early	mid early	
2012	86.31*a*	84.94*a*	80.09*b*	83.78*f*
2013	141.11*a*	120.02*b*	99.44*c*	120.20*d*
2014	97.27*a*	95.02*a*	97.95*a*	96.74*e*
2015	227.42*a*	184.34*b*	118.68*c*	176.81*a*
2016	119.19*a*	41.70*c*	47.95*b*	69.61*g*
2017	55.40*a*	36.99*b*	28.77*c*	40.38*i*
2018	176.19*a*	156.18*b*	122.61*c*	151.66*b*
2019	169.11*a*	150.70*b*	108.23*c*	142.68*c*
2020	77.48*a*	52.06*c*	73.21*b*	67.58*h*
Mean	127.72*a*	102.44*b*	86.33*c*	

Means with the same letter do not differ significantly.

as indicated using Selyaninov's coefficient, the nitrate content in tubers was significantly higher than during wet years (Table 5). Previous studies have confirmed the tendency to a greater accumulation of nitrates in tubers in the face of a precipitation deficit compared to nitrate excess during the growing season (Grudzińska, Zgórska 2008). This is due to, inter alia, the lability of mineral nitrogen forms in the soil, i.e. their lower movability in the face of limited rainfall, which results in a greater uptake by plants. On the other hand, a lower nitrate content recorded during wet years could be related to the displacement of a portion of mineral nitrogen beyond the root system of potato plants, a phenomenon which has already been observed by researchers (Jamaati-e-Somarin et al. 2009, Hmelak Gorenjak et al. 2014, Kołodziejczyk 2015).

The nitrate content in potato tubers often varies significantly, mainly due to the use of nitrogen during mineral fertilization; however, a significant influence of the genotypic properties and weather conditions can also be observed (Cieślik 1995, Jabłoński 2006, Jarych-Szyszka 2006, Murawa et al. 2008, Ierna 2009). As potatoes are a significant component of the human diet in many parts of the world, a high nitrate level in tubers may reduce their nutritional value, thereby having a negative effect on human health (Gajewska et al. 2009, Hmelak Gorenjak, Cencič 2013). Studies have shown that high vitamin C content decreased the harmful impact of nitrates, as it reduced nitrites to nitric oxide, eliminating the precursors of the nitrite nitrosation reaction, the compounds which have mutagenic and carcinogenic effects (Massey et al. 1982, Traczyk 2000, Tymczyna, Maińska 2001, Mensinga et al. 2003). In studies by Cieślik (1994) and Mazurczyk, Lis (2004), a significant correlation between the vitamin C content and nitrates was observed, with a significant negative correlation indicated between the content of these elements in tubers, i.e. an increase in the vitamin C content was accompanied by a decrease in the nitrate content. In a study by Mazurczyk and Lis (2004), a 5-unit decrease in the nitrate level was observed when the vitamin C content was increased by one unit (mg kg^{-1}). Cieślik (1994) found that a one-unit increase in the vitamin C content was accompanied by a 25-unit decrease in the vitamin C content. This research did not confirm a significant correlation between the vitamin C content and nitrates, but it was rather a tendency, as illustrated by the low values of the correlation coefficients: from 0.205 to 0.350 (Table 6). The negative correlation between the vitamin C content and the nitrate content in tubers was demonstrated by the fact that a one-unit increase of the vitamin C content (mg kg^{-1} fresh weight) was accompanied by a 0.03-unit decrease in the nitrate content for the very early cultivar group and a 0.54-unit decrease for the medium early cultivar group. In general, the existence of a negative relationship between the vitamin C and nitrate content is beneficial for the consumer, as it widens the ratio between these components. According to Mazur et al. (1993), nitrosamines do not appear in tubers if two parts (units) of vitamin C are allocated to one part of nitrate. Other studies have also demonstrated an improvement of the nutritional value of potato tubers through the widening of the ascorbate and nitrate content ratio (IAN ascorbate – nitrate index) Hajslova et al. (2005), Pokluda (2006), Wadas et al. (2012), Wszelaczyńska et al. (2020*b*). These studies indicated that tubers from the early and medium-early cultivar groups had a favourable vitamin C to nitrate ratio of at least 2 units, i.e. with a relatively longer growing season (Table 7), which was confirmed by Mazurczyk and Lis (2004) as well as our previous research (Trawczyński, Wierzbicka 2012). The variability of the ratio between the vitamin C level and nitrates in comparison to the analysed years was also significant,

Table 6

Relationships between the content of vitamin C (x) and nitrates (y) in potato tubers

Group of cultivars	Number of cultivars	Regression equation	r
Very early	6	Y=134.48-0.0329x	0.205
Early	12	Y=189.67-0.4153x	0.315
Mid early	21	Y=196.77-0.5492x	0.350

Table 7

Ratio of vitamin C and nitrates $NaNO_3$ (mg kg^{-1}) in maturity groups and years. Years 2012-2020

Years	Group of maturity			Mean
	very early	early	mid early	
2012	2.91*a*	2.92*a*	2.04*b*	2.62*d*
2013	1.49*c*	1.65*b*	1.98*a*	1.71*f*
2014	1.80*b*	1.78*b*	2.01*a*	1.86*e*
2015	0.90*b*	1.09*b*	1.68*a*	1.22*h*
2016	1.56*b*	4.81*a*	4.56*a*	3.64*b*
2017	4.27*c*	6.40*b*	8.26*a*	6.31*a*
2018	1.23*c*	1.41*b*	1.69*a*	1.44*g*
2019	1.20*b*	1.38*b*	1.92*a*	1.50*g*
2020	2.05*c*	3.95*a*	2.45*b*	2.82*c*
Mean	1.93*c*	2.82*b*	2.95*a*	

Means with the same letter do not differ significantly.

and mainly resulted from the increased nitrate accumulation in tubers during the years with periodical precipitation deficits. The greatest reduction in the ratio of vitamin C to nitrates was observed in the years 2015, 2018, and 2019, which were generally dry (K <1). In five out of the nine analysed years, the ratio of vitamin C to nitrates was below 2, which could reduce the nutritional value of the potato tubers.

CONCLUSIONS

1. Significant differences were found in the vitamin C content and nitrates in tubers in relation to the length of the growing season of the cultivars; the highest level of these components was observed in the very early group, and the lowest in the medium-early group.

2. In the analysed years, the influence of the weather factor on the variability of the vitamin C content and nitrates in tubers was greater than that of the maturity group of the cultivars.

3. In the years 2012, 2016, 2017, and 2020, a favourable ratio of vitamin C to nitrates was observed, with more than two parts of vitamin C per one part of nitrates.

4. The cultivars from the early and mid-early group were characterized by a significantly more favourable ratio of vitamin C to nitrates than those belonging to the very early group.

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