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Effect of foliar fertilization using micronutrient fertilizers on the content of nitrates(V) and nitrites(III) in potato tubers

Wpływ nawożenia dolistnego nawozami mikroelementowymi na zawartość azotanów(V) i azotynów(III) w bulwach ziemniaka

Summary. The research was based on a 3-year field experiment carried out in south-eastern Poland, in 2013–2015, on brown, slightly acidic soil. The experiment was established by the randomized sub-block method, where the first-order factors were foliar fertilization: (A) Fortis Duotop Zn Mn + Fortis Aminotop, (B) Fortis B Mo + Ferti Agro, (C) Fortis Zn Mn + Fortis B Mo and (0) standard object, without foliar fertilization. The factors of the second order were 4 edible potato cultivars ('Viviana', 'Vineta', 'Jelly' and 'Agnes'). Foliar application of all fertilizer combinations contributed to the reduction of the content of nitrates and nitrites in potato tubers. However, the response of cultivars to foliar fertilization was varied. The medium late cultivar 'Jelly' was characterized by the lowest tendency to accumulate nitrates, while the early cultivar 'Vineta' was the highest. The highest content of both nitrates and nitrites in tubers was recorded in the dry year, with a significant shortage of rainfall during the potato growing season, and the lowest in the year, about wet June, and September.

Key words: nitrates, nitrites, foliar feeding, cultivars, potato

INTRODUCTION

Nitrates and nitrites are natural components of tubers that arise as a result of metabolic disturbances in plants or get to them from a polluted environment [Correia et al. 2010, Zarzecka et al. 2016, Kujawska et al. 2018]. They are precursors of toxic N-nitroso compounds found in food, an example of which is 1,2-dimethylnitrosamine, which causes liver damage and induction of tumors [Kościańska and Rodecka-Gustaw 2011, Brkić et al. 2017]. The risk of high nitrate content is related to the fact that these compounds are precursors to the highly toxic nitrite that is produced by the reduction of nitrates. They cause, inter alia, methemoglobinemia (Latin *methemoglobinemia*) and vitamin A and B deficiency. Moreover, they may lower blood pressure and destroy carotenoids [Boncler et al. 2010, Correia et al. 2010]. However, only 5–20% of consumed nitrates are converted into toxic nitrites. Their harmfulness is related to the oxidation of hemoglobin in the blood and the formation of methemoglobin (metHb), which prevents oxygen transport, and is also associated with the formation of carcinogenic, mutagenic and embryotoxic nitrosamines. The binding and formation of methemoglobin is dependent on blood concentration and time. Methemoglobin concentration greater than 50% may lead to coma and death [Gorenjak and Cencič 2013]. The content of nitrates in potato tubers fluctuates around 100–740 mg of $NaNO_3$ kg^{-1} of fresh weight of tubers. Mozolewski and Smoczyński [2004] showed that the level of nitrates and nitrites in potatoes can be reduced by 18–40% and 25–75%, respectively, after pre-treatment of this material (washing, peeling, blanching, rinsing in water). Thermal treatment of potato tubers reduces the number of nitrates by 16–62% and nitrites by 61–98%. About 75% of the amount of these compounds is removed during cooking, and 45% – during digestion [Du et al. 2007]. According to the WHO, the acceptable daily intake of nitrates should not exceed 3.7 mg NO_3 kg^{-1} of body weight. The FAO/WHO Expert Committee on Food Additives [JECFA 2002] set the daily adult dose for nitrates at 0.0–3.7 mg, and for nitrite at 0.0–0.7 mg kg^{-1} respectively 1 body weight. For animals, this value is lower and amounts to 0.07 mg NO_2 kg^{-1} body weight [Boncler et al. 2010]. Acceptable Daily Intake (ADI) for an adult weighing 70 kg should not exceed 260 mg of nitrate and 49 mg of nitrite [JECFA 2002]. On the other hand, the dose of nitrates exceeding 8–11 mg kg^{-1} of body weight d^{-1} is lethal [Burt et al. 1993]. The content of nitrogen compounds in tubers depends on the genetic properties of potato cultivars, meteorological conditions during the growing season and applied agricultural practices [Lachman et al. 2005, Ierna 2009, Kołodziejczyk 2014, Pobereżny et al. 2015, Barbaś and Sawicka 2016, Zarzecka et al. 2016].

Potato cultivation under conditions of high nitrogen fertilization has a high potential for N loss. On the other hand, high NO_3^- concentration in potato tubers is a significant problem for potato exporters and farmers in Cyprus, Israel, and Egypt [Elrys et al. 2018]. Based on Polish and German standards, if the content of NO_3^- in tubers exceeds 180 and 200 mg NO_3^- kg^{-1} fresh weight, then they are not suitable for human consumption [Gorenjak et al. 2014]. Increased accumulation of NO_3^- in potato tubers causes many diseases, both in humans and animals, and poses a threat to the general health of society [JECFA 2002, Boncler et al. 2010, Chen et al. 2017]. It is therefore important to find new, different approaches to reduce NO_3^- accumulation to an acceptable limit in tubers. Bearing in mind the chemical monitoring of food contamination, the development of an ecological system in potato cultivation and the still high potato consumption, research was undertaken to determine the effect of biofortification of potato plants with micronutrient fertilizers, applied in foliar form, on the content of nitrates and nitrites in the tubers of several potato cultivars belonging to different groups of early years. Therefore, an alternative research hypothesis was put forward, which assumes that the application of micronutrient fertilizers in the foliar form will reduce the content of nitrates and nitrites in potato tubers and increase the NUE of potato by inhibiting AOB and minimizing gaseous emissions, against the null hypothesis that fertilization these fertilizers will not have a significant effect on the value of both these forms of nitrogen in potato tubers.

MATERIAL AND METHODS

The study was based on a 3-year field experiment conducted in south-eastern Poland (49°40'N 21°54'E) in 2013–2015 on brown, slightly acid soil [Mocek 2015]. The experiment was established using the randomized sub-block method, in the dependent, split-plot design, in three replications. The factors of the first order were foliar fertilization with the use of the following fertilizers: Fortis Duotop Zn Mn + Fortis Aminotop (A), Fortis B Mo + Ferti Agro (B), Fortis Duotop Zn Mn + Fortis B Mo (C) and the standard object (0) without foliar fertilization. The factors of the second order were potato cultivars: 'Viviana', 'Vineta', 'Jelly', 'Agnes', from different earliness groups.

Characteristics of fertilizers

The foliar fertilizers were characterized by the following chemical composition:

– Ferti Agro is a fertilizer containing the following amounts of ingredients: nitrogen – 10%, phosphorus – 45%, potassium – 5%, boron – 0.05%, copper – 0.1%, iron – 0.05%, manganese – 0.1%, zinc – 0.4%, magnesium – 2%, sulfur – 8.0%, molybdenum – 0.01%, as well as amino acids and vitamins [Ferti Agro 10/45/5 2013],

– Fortis Aminotop preparation contains 9% organic nitrogen, soluble amino acids, aspartic acid – 0.46%, glutamic acid – 3.50%, serine – 0.21%, histidine – 0.04%, glycine – 4.16%, threonine – 0.04%, alanine – 1.71%, arginine – 0.11%, tyrosine – 0.47%, valine – 0.09%, methionine – 0.06%, phenylalanine – 0.24% , isoleucine – 0.28%, leucine – 0.29%, lysine – 0.23%, hydroxyproline – 0.77%, proline – 1.36% [Fortis Aminotop 2013],

– Fortis B Mo is a fertilizer containing the greatest amount of boron – 11% and molybdenum – 0.37% [Fortis B Mo 2013],

– the preparation Fortis Duotop Zn Mn contains: zinc in the amount of 7.1%, manganese – 5.1%, copper – 0.033%, boron – 0.024%, molybdenum – 0.003% and magnesium – 0.2% [Fortis Duotop Zn Mn 2013].

Characteristics of the cultivars

The characteristics of the tested cultivars are presented in table 1.

Table 1. Description of potato cultivars grown in the experiment

Cultivars	Maturity group	Color of skin	Colour of the flesh	Shape of the tubers	Mesh depth	Blight resistance [9°scale]	PVY resistance [9°scale]	PLRV resistance [9°scale]
'Viviana'	very early	yellow	light yellow	round--oval	shallow	2	5–6	5–6
'Vineta'	early	yellow	light yellow	oval	shallow	2	8	8
'Agnes'	medium early	yellow	light yellow	oblong--oval	shallow	5.5	5.5	7
'Jelly'	medium late	yellow	light yellow	oval	shallow	6	5.5	5.5

Source: Grudzińska and Zgórska 2008, Wadas et al. 2012

Growing conditions

The forecrop of the potato was spring barley. After harvesting the forecrop, stubble cultivation was applied, and in autumn, plowing combined with manure plowing in a dose of 25 t ha^{-1} and phosphorus-potassium fertilizers in the amount of 43.6 kg P ha^{-1} and 124.5 kg K ha^{-1}. Nitrogen fertilization, in the dose of 80 kg N ha^{-1}, was performed in the spring before planting. The seed potato in the C/A class was planted at the end of April at a spacing of 70 × 38 cm. The size of the plots to be harvested was 15 m^2. The foliar fertilizers were applied according to the producers' recommendations, starting from the third decade of May (BBCH 29 phase) until the beginning of fruit formation (BBCH 71 phase). Depending on the combination of the experiment, micronutrient fertilizers were used in the first and third decade of June and in the first, second and third decade of July. The Ferti Agro fertilizer was applied in a dose of 3 kg ha^{-1}, four times during potato vegetation, every 7 days, starting from the side shoots development phase. Fortis Aminotop was brought in the amount of 2–3 dm^3 ha^{-1}, four times, starting from the moment the plant reached a height of 15–20 cm, every 10–15 days. Fortis B Mo was applied at a dose of 1–1.5 dm^3 ha^{-1}, twice: the first dose in the period from shoot formation to row closure (phase 29 BBCH), and the second dose – during the period of tuber and inflorescence formation (51 BBCH) [Bleinholder et al. 2001]. The Fortis Duotop Zn Mn fertilizer was also applied twice when the plants were 10–15 cm tall (29 BBCH phase) and 15 days later, at a dose of 2–3 dm^3 ha^{-1} (40 BBCH phase). The object without fertilization was sprayed with clean water. The amount of the working liquid was 300 dm^3 ha^{-1}. No adhesion promoter was used. A battery sprayer was used to perform the runs, equipped with a flat-fan sprayer with a flow rate of 0.35–0.65 dm^3 min^{-1} and a pressure of 0.1–0.2 MP.

Plant care and protection treatments were performed in accordance with good agricultural practice [Ministry of Agriculture… 2004]. After planting the tubers, mechanical and chemical treatments were applied, consisting in covering ridges just before emergence, and then preparate Plateen 41.5 WG was applied to the newly formed soil and formed ridges, at a dose of 2 kg ha^{-1}. This preparation contains metribuzin and flufenacet, acting against dicotyledonous and monocotyledonous weeds. It was applied to moist soil so that it could move into the soil and be taken up by weeds. During the potato vegetation period, treatments were performed against the Colorado potato beetle as well as alternariosis (dry and brown potato leaves spot) and late blight in accordance with IOR-PIB recommendations (tab. 2).

The preparations used in the experiment were recommended to plant cultivation by the Ministry of Agriculture and Rural Development [Ustawa z dnia 7 maja 2020 r.]. The tubers were harvested in the phase of physiological maturity of potato tubers (98 in the BBCH scale). This date was at the end of August (for very early and early cultivars) and mid-September (for medium-early and mid-late cultivars). During the harvest, representative samples of 50 medium-sized tubers were collected for chemical analyzes [Grudzińska and Zgórska 2008].

Before setting up the experiment, 20 primary soil samples were collected every year, making up one general sample, weighing approximately 0.5 kg [PN-R--04031:1997]. In the soil samples collected in this way, the following values were determined: particle size distribution, pH in 1 mol KCl dm^{-3} [PN-ISO 10390:1997P], organic carbon content ($C_{organic}$) using the Tiurin method [KQ/PB-34], and on its basis, the humus content in the soil [Mocek 2015] and the content of P [PN-R-04023:1996P], K [PN-R-04022:1996/Az1:2002P], Mg [PN-R-04020:1994/Az1:2004P] was determined.

Table 2. Doses of fungicides and insecticides in plant potato protection in 2013–2015

2013	2014	2015
fungicides		
– Infinito 687.5 SC (propamocarb hydrochloride + fluopicolide) (625 +62.5) – 1.5 dm^3 ha^{-1} – Ridomil Gold MZ 67.8 (mancozeb + metalaxyl) (640 + 38.5) – 2 kg ha^{-1} – Infinito 687.5 SC (propamocarb hydrochloride + fluopicolide) (625 +62.5) – 1.5 dm^3 ha^{-1}	– Acrobat MZ 69 WG (dimethomorph + mancozeb) (90 + 600) – 2.0 kg ha^{-1} Infinito 687.5 SC (propamocarb hydrochloride + fluopicolide) (625 + 62.5) – 1.5 dm^3 ha^{-1} – Acrobat MZ 69 WG (dimethomorph + mancozeb) (90 + 600) – 2.0 kg ha^{-1}	– Acrobat MZ 69 WG (dimethomorph + mancozeb) (90 + 600) – 2.0 kg ha^{-1} – Infinito 687.5 SC (propamocarb hydrochloride + fluopicolide) (625 + 62.5) – 1.6 dm^3 ha^{-1} – Acrobat MZ 69 WG (dimethomorph + mancozeb) (90 + 600) – 2.0 kg ha^{-1}
insecticides		
– Apacz 50 WG (clothianidin 500) – 0.04 kg ha^{-1} – Proteus OD 110 (thiacloprid + deltamethrin) (100 + 10) – 0.4 dm^3 ha^{-1}	– Actara 25 WG (thiamethoxam 250) – 0.07 kg ha^{-1} – Nuprid 200 SC (imidacloprid 200) (0.16 dm^3 ha^{-1}) – Apacz 50 WG (clothianidin 500) – 0.05 kg ha^{-1}	– Actara 25 WG (thiamethoxam 250) – 0.08 kg ha^{-1} – Apacz 50 WG (clothianidin 500) – 0.04 kg ha^{-1} – Proteus OD 110 (thiacloprid + deltamethrin) (100 + 10) – 0.35 dm^3 ha^{-1}

Soil sampling and soil analysis

Chemical analyzes of tubers

The content of nitrates was determined using an ion-selective nitrate electrode and a silver chloride reference electrode [Kunsch et al. 1981], while the content of nitrites was determined chemically using the colorimetric method with Griess reagent. The absorbance of the samples was measured at a wavelength equal to λ = 538 nm. The determination used direct reduction of nitrates(V) to nitrates(III) with metallic cadmium (according to the PN-92/A-75112 standard corresponding to the ISO 6635-1984 standard). All samples were analyzed in duplicate [Horwitz 2006, Boncler et al. 2010].

Meteorological conditions

The meteorological conditions in the years of the study were varied. The year 2013 was characterized by very dry July and August, in the period of maximum tuber yield accumulation, while June and September were characterized by excess rainfall. During the entire growing season, the total rainfall accounted for 90.3% of the multi-year rainfall total, the lowest level of rainfall in relation to the multi-year standard was observed in July. The average of air temperature in the third decade of April, when potatoes were planted, was high and amounted to 15°C. Relatively high temperatures in the last decade of April and in May were conducive to rapid potato emergence. In that year, the average temperature was 0.9°C lower than the long-term average (tab. 3).

In 2014, the months of April and May were cold and wet, June and July were quite warm, and July was characterized by excess rainfall in relation to the long-term norm. 2014 was characterized by excess rainfall in relation to the potato's water requirements. The sum of precipitation, in comparison with the long-term average, was the highest in comparison with the remaining years of the study. The temperature distribution during the growing season was favorable for the development of the potato. The average of air temperatures showed a slight deviation from the long-term mean, and the mean temperature was 1.2°C higher than the long-term mean (tab. 3).

The year 2015 was characterized by the lowest total rainfall during the study period. The sum of rainfall accounted for 70.2% of the long-term average. Precipitation in the second growing season did not ensure even 50% of the demand for water by potato plants. The months of June and July were dry months, and August was extremely dry. In turn, May was a very humid month, and in September the rainfall exceeded the long-term standard. In August, the average air temperature was 2.2°C higher than the long-term average (tab. 3).

Table 3. Qualification of the potato vegetation period according to the Sielianinov hydrothermal coefficient according to the meteorological station in Krosno 2013–2015

Month	Rainfall (mm)			Air temperature (°C)			Hydrothermal coefficient of Sielianinov*		
	2013	2014	2015	2013	2014	2015	2013	2014	2015
April	30.6	63.7	28.2	9.5	10.0	8.3	1.1	2.1	1.1
May	80.5	119.0	98.2	14.5	13.4	12.1	1.8	2.9	2.6
June	126.5	52.9	26.2	17.6	16.0	15.7	2.4	1.1	0.6
July	30.2	164.2	63.1	18.7	19.6	20.1	0.5	2.7	1.0
August	30.7	67.9	10.6	18.6	17.4	20.5	0.5	1.3	0.2
September	92.5	31.3	108.0	11.6	14.9	15.3	2.7	0.7	2.4
Mean	–	–	–	15.1	15.2	15.3	1.5	1.8	1.3

* coefficient was calculated according to the formula: $k = 10P / \Sigma t$ [Skowera et al. 2014]. Ranges of values of this index were classified as follows: extremely dry − $k \leq 0.4$; very dry – $07 \leq k < 0.4$; dry − $1.0 \leq k < 0.7$; rather dry − $1.3 \leq k < 1.0$; optimal − $1.6 \leq k < 1.3$; rather humid − $2.0 \leq k < 1.6$; wet − $2.5 \leq k < 2.0$; very humid − $3.0 \leq k < 2.5$; extremely humid − $3.0 > k$

STATISTICAL ANALYSIS

The obtained results were statistically calculated based on the three-factor analysis of variance (ANOVA) model and multiple t-Tukey tests. The calculated p values determine the significance and size of the influence of the examined factors on the differentiation of the results of the analyzed variables by comparing them with the most commonly accepted significance levels α = 0.05. For detailed analyzes based on t-Tukey's multiple tests, the significance level was α = 0.05. Letter indicators at averages define the so-called homogeneous groups (statistically homogeneous). The presence of the same letter index with the means (at least one) means that there is no statistically significant difference between them. Subsequent letter indices a and b define groups of means in descending order. HSD values play an auxiliary role, allowing for a quantitative estimation of the differences between the means. In addition, the coefficients of variation for the entire experiment (for each variable) CV (%) or RSD (relative standard deviation) were calculated. They are measures of random variability in the conducted experiment [Laudański and Mańkowski 2007].

RESULTS

Soil conditions

The experiment was carried out on brown soil made of flysch sediments with the mechanical composition of clay dust [Mocek 2015]. This soil was slightly acidic (pH 5.69 in 1M KCl).

Table 4. Conditions of field experiences, abundance of soil available phosphorus, potassium, magnesium, $CaCO_3$, pH of the soil and the content of humus

Years	The content of available forms (g kg^{-1} in dry mass of soil)			$CaCO_3$ (g kg^{-1})	Humus (g kg^{-1})	pH (1M KCl)	The content of micronutrients (mg kg^{-1} of soil)			
	P_2O_5	K_2O	Mg				Cu	Mn	Zn	Fe
2013	126	200	197	0.2	27.1	5.66	5.6	175.2	14.3	1591.0
2014	120	200	195	0.2	25.5	5.70	5.9	174.2	14.5	1575.0
2015	125	202	199	0.1	27.2	5.70	5.3	175.0	14.4	1589.0
Mean	124	201	197	0.2	26.6	–	5.6	174.8	14.4	1585.0

Source: own study based on the results of the District Chemical-Agricultural Station in Rzeszów

The abundance of available phosphorus and potassium in the studied soil was average, the abundance in magnesium was very high, and in copper, manganese, iron and zinc – average. The humus content in the arable layer was high and amounted to 26.6 g kg^{-1} on average (tab. 4). The results of the research allowed the soil to be included in the valuation class IVb, a good rye complex.

Content of nitrates

A significant, beneficial effect of foliar fertilization was revealed in the form of a reduction in the content of nitrates in potato tubers in relation to the reference object (tab. 5).

This proves the advantageous aspect of using multi-component foliar fertilizers in potato cultivation. The cultivars studied significantly influenced the value of this characteristic in potato tubers. The early 'Vineta' cultivar had the highest concentration of nitrates in tubers, while the mid-late 'Jelly' cultivar had the least (tab. 5).

The significance of the interaction of cultivar × fertilization technologies has been proven. Cultivar 'Agnes' reacted with the highest reduction of nitrates in the fertilizer combination: Fortis B Mo + Ferti Agro, a significantly lower effect was obtained in the other two fertilizer combinations. A similar reaction to fertilization technologies was shown by the 'Jelly' cultivar, where, however, the B and C technologies turned out to be homogeneous in terms of the value of this feature. The very early cultivar 'Viviana' responded best to fertilization with Fortis Duotop Zn Mn + Fortis Aminotop fertilizers, while in the B technology with the use of Fortis B Mo + Ferti Agro fertilizers, a significant increase in nitrate concentration was observed, compared to the standard object. The early cultivar 'Vineta' responded to technology A with the greatest reduction of nitrates with the use of Fortis Duotop Zn Mn + Fortis Aminotop fertilizers; technology B with the use of Fortis B Mo + Ferti Agro fertilizers turned out to be homogeneous in terms of the value of this feature (tab. 5).

Table 5. Effect of cultivars, fertilization technology and years on the content of nitrates in the fresh mass of potato tubers (mg kg^{-1})

Fertilization technology*	Cultivars				Years			Mean
	'Agnes'	'Jelly'	'Viviana'	'Vineta'	2013	2014	2015	
0	101.30^{a}**	66.36^{a}	106.94^{b}	147.30^{a}	79.19^{a}	72.54^{a}	164.72^{a}	105.48^{a}
A	88.32^{b}	51.62^{b}	97.89^{c}	139.18^{b}	62.88^{a}	69.03^{a}	150.84^{a}	94.25^{b}
B	80.98^{c}	46.10^{c}	113.69^{a}	140.74^{b}	58.24^{a}	80.30^{a}	147.87^{a}	95.38^{b}
C	85.99^{b}	46.36^{c}	104.92^{b}	144.66^{a}	64.05^{a}	73.11^{a}	149.29^{a}	95.49^{b}
Mean	89.16^{c}	52.61^{d}	105.86^{b}	142.97^{a}	66.10^{c}	73.68^{b}	153.18^{a}	97.65

* 0 – standard facility, without foliar fertilization; A – Fortis Duotop Zn Mn + Fortis Aminotop; B – Fortis B Mo + Ferti Agro; C – Fortis Duotop Zn Mn + Fortis B Mo; $HSD_{0.05}$ for technology (T) – 1.53; for cultivars (C) – 1.53; for years (Y) – 1.21; T × C – 4.12; RSD (%) – 2.55; ** Letter indicators at averages define the so-called homogeneous groups (statistically homogeneous). The occurrence of the same letter index with the means (at least one) means no (or no) statistically significant difference between them.

Atmospheric conditions in the research years significantly modified the concentration of nitrates in potato tubers. The smallest number of them were in tubers harvested in 2013, when July and August were dry, and June and September – wet. Their content was more than twice as high as in 2013, it was found in the extremely dry year of 2015 (tab. 5).

The response of the studied cultivars to foliar fertilization technologies was varied. In tubers of 'Agnes' and 'Jelly' varieties, a decrease in the content of nitrates in tubers was observed after the application of the fertilizers Fortis Duotop Zn Mn + Fortis Aminotop and Fortis B Mo + Ferti Agro by 20.1% and 30.5%, relation to the standard object. In the case of the cultivars 'Viviana' and 'Vineta', the use of Fortis Duotop Zn Mn + Fortis Aminotop fertilizers, by 8.5% and 5.5%, respectively, had the greatest impact on reducing the value of this characteristic. In the case of the cultivar 'Viviana', a significant increase in the content of nitrates in potato tubers was observed after the application of Fortis B Mo + Ferti Agro fertilizers (fig. 1).

The coefficient of variation for the entire experiment, V (%) or RSD (relative standard deviation) was very low and amounted to RSD = 2.55%, which proves that the experiment was very carefully conducted. It is a measure of the random variability of an experience.

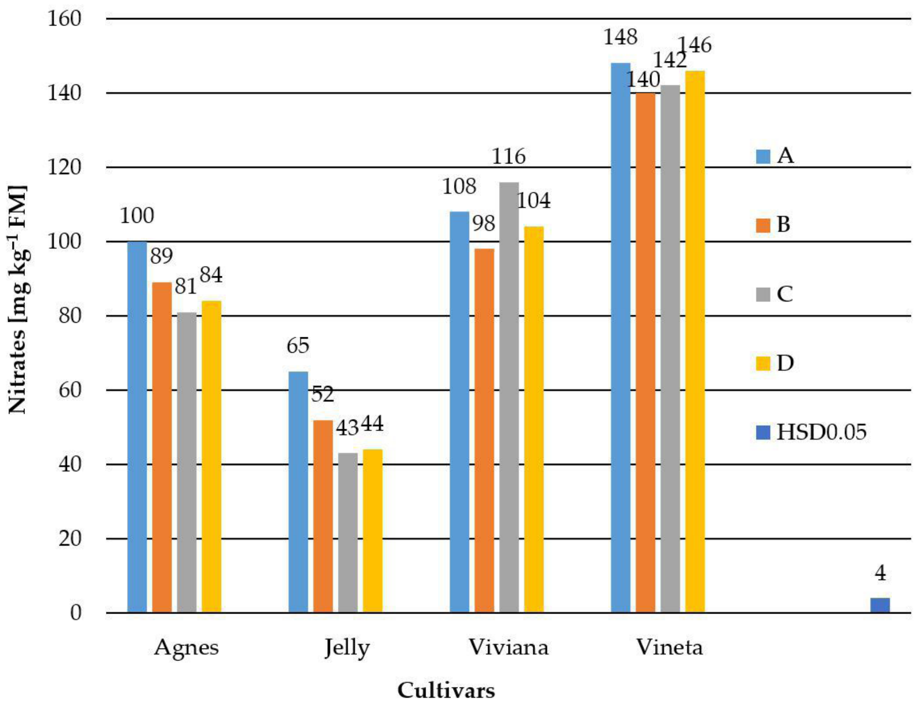

Figure 1. Effect of fertilization technologies and cultivars on nitrates content in the fresh mass of potato tubers

(A – Fortis Duotop Zn Mn + Fortis Aminotop; B – Fortis B Mo + Ferti Agro; C – Fortis Duotop Zn Mn + Fortis B Mo; D – standard object without foliar fertilization)

Nitrite content

The positive, beneficial effect of foliar fertilization with multicomponent, micronutrient fertilizers was revealed in the form of a reduction in the nitrite content in potato tubers in relation to the standard object. The lowest content of this nitrogen form was found after using the combination of Fortis B Mo + Ferti Agro fertilizers, followed by Fortis Duotop Zn Mn + Fortis Aminotop and Fortis Duotop Zn Mn + Fortis B Mo (tab. 6). This proves the advantageous aspect of the combined use of multi-component, micronutrient fertilizers in foliar form.

The cultivars studied significantly influenced the content of nitrites in potato tubers. The most harmful nitrites were accumulated by the very early cultivar ‘Viviana’, and the least early ‘Vineta’, while the next places were taken by the medium early ‘Agnes’ and the medium late ‘Jelly’, which turned out to be homogeneous in terms of the value of this feature (tab. 6).

Atmospheric conditions in the research years significantly modified the nitrite content in potato tubers. The lowest number of nitrites in tubers was found in the wet year 2014, the highest in the dry year 2015 (tab. 6).

The coefficient of variation V (%) or RSD, which is a measure of random variation for nitrates, was low and amounted to RSD = 14.98%, which proves that the research was thoroughly conducted.

Table 6. Influence of fertilization technology, cultivars, and years on nitrite content in the fresh mass of potato tubers (mg kg^{-1})

Fertilization technology*	Cultivars				Years			Mean
	'Agnes'	'Jelly'	'Viviana'	'Vineta'	2013	2014	2015	
0	4.65^{a}**	4.32^{a}	5.20^{a}	4.00^{a}	4.28^{a}	3.00^{a}	6.65^{a}	4.59^{a}
A	4.25^{a}	4.28^{a}	4.95^{a}	3.95^{a}	4.15^{a}	2.85^{a}	6.50^{a}	4.42^{b}
B	4.28^{a}	4.25^{a}	4.88^{a}	3.87^{a}	3.98^{a}	2.40^{a}	6.48^{a}	4.31^{c}
C	4.30^{a}	4.30^{a}	5.15^{a}	3.98^{a}	4.00a	2.30^{a}	6.52^{a}	4.36^{b}
Mean	4.37^{b}	4.29^{b}	5.04^{a}	3.95^{c}	4.10^{b}	2.63^{c}	6.54^{a}	4.42

* 0 – standard facility, without foliar fertilization; A – Fortis Duotop Zn Mn + Fortis Aminotop; B – Fortis B Mo + Ferti Agro; C – Fortis Duotop Zn Mn + Fortis B Mo; $HSD_{0.05}$ for technology (T) – 0.26; for cultivars (C) – 0.26; for years (Y) – 0.20; RSD (%) – 14.98; ** Letter indicators at averages define the so-called homogeneous groups (statistically homogeneous). The occurrence of the same letter index with the means (at least one) means no (or no) statistically significant difference between them

DISCUSSION

The potato is considered to be a nitrogen (N) intensive plant with a low N-efficiency (NUE) utilization. Current research has introduced an excellent approach by combining foliar fertilization with micronutrient fertilizers with soil NPK fertilizers to maximize potato tuber and NUE yields and minimize tuber nitrate accumulation (NO_3^-). The effect of these fertilizers on the availability of N in the soil and gaseous emissions (NH_3 and N_2O) were investigated under incubation conditions [Asef et al. 2019, Elrys et al. 2021]. The use of foliar fertilization in our research gave a beneficial effect in the form of lowering the level of both nitrates and nitrites in potato tubers. These results are confirmed by Ciećko et al. [2010]. In turn, Wadas et al. [2012] believe that both single-component, multi-component and complex fertilizers increase the content of nitrates. Grudzińska and Zgórska [2008] suggest that high doses of nitrogen fertilizers combined with unfavorable weather conditions during the growing season may increase the nitrate content even up to 1200 mg NO_3^{-1} kg^{-1}.

Nitrification inhibitors (NI) are considered as N stabilizers in the world. These preparations are designed to block the activity of nitrifying bacteria in the conversion of NH_4^+ to NO_3^- slowing the release of NO_3^- to the soil [Ruark et al. 2018]. Probably the multi-component, micronutrient fertilizers used in the experiment have an activity in preserving NW into less mobile NH_4^+ forms into the soil, reducing the content of NO_3^- forms and increasing efficiency through the use of N^- (NUE) by plants [Brkić et al. 2017]. The use of other forms of nitrogen in compound fertilizers could inhibit the growth of nitrate and nitrite forms in potato tubers. This is confirmed by the results of Elrys et al. [2021]. Souza et al. [2020] report that agronomic performance is better when potato cultivation is fed with nitrogen fertilizer mixed with NI. Therefore, the previously formulated hypothesis that the use of multi-component, micronutrient fertilizers will be very useful in minimizing the accumulation of NO_3^- in tubers and increasing the potato NUE by reducing the release of NO_3^- to the soil turned out to be positively verified. However, the indirect effect of these fertilizers on minimizing NO_3^- accumulation in tubers has not been investigated. In addition to using chemical compounds as NI, it is also necessary to look for other natural compounds that are cheaper and environmentally friendly. For example, Elrys et al. [2018] proved that using moringa extract (*Moringa oleifera*) they obtained an AOB inhibition effect abundantly in the soil, which is an important strategy to reduce nitrogen losses from soil, and thus managed to improve NUE and reduce NO_3^- content in tubers. Similarly, Ashraf et al. [2019] reported that the use of urea coated with moringa oil is highly effective in reducing losses of N.

Many authors believe that the excessive accumulation of nitrates is characteristic of those plant species and cultivars that have a shorter growing season [Grudzińska and Zgórska 2008, Barbaś and Sawicka 2016, Haddad et al. 2016, Elrys et al. 2018]. Moreover, it is a feature dependent on the variety [Simson et al. 2016]. In the conducted studies, the content of these compounds was low [JECFA 2002]. Zarzecka et al. [2016] found the content of nitrates in potato tubers at the level of 103.66–117.72 mg NO_3 kg^{-1}. Barbaś and Sawicka [2016] noted a higher content of nitrates in the medium early 'Irga' variety, compared to the medium late 'Fianna' variety, but the use of herbicides did not modify the value of this feature. Wadas et al. [2012] obtained stable results at the level of 80.6 to 82.1 mg NO_3 kg^{-1}, while Lachman et al. [2005] and Hamouz et al. [2005] found greater differences in the content of nitrates, ranging from 70.2 to 199.2 mg NO_3 kg^{-1}, depending on the cultivar. However, these values are much lower than for other agricultural products, such as: lettuce (1500–3000 mg kg^{-1}), cabbage (1000–6500 mg kg^{-1}) or sugar beet (1400–3200 mg kg^{-1}) [Haddad et al. 2016]. According to Correira et al. [2010], food of plant origin is the main source (80–95%) of these compounds in human food. The conducted research showed a significant influence of genotype on the content of nitrates and nitrites in potato tubers. Early varieties had a higher their content than the late ones. This is confirmed by Grudzińska and Zgórska [2008] and Ierna [2009]. Lachman et al. [2005] obtained the highest nitrate content of 199.2 NO_3 kg^{-1}, and the lowest 70.2 and 94.5 NO_3 kg^{-1} depending on the cultivar, while Mareček et al. [2008] – in the range from 50.9 to 128.3 mg NO_3 kg^{-1} fresh weight of tubers. Elrys et al. [2018, 2021] noted the highest accumulation of nitrates with the use of nitrogen in the form of urea alone, compared to the used ammonium sulphate and foliar application of molybdenum and salicylic acid.

Nitrites are much more dangerous to health than nitrates, but the content of these compounds in the conducted studies was low and fell within the lower limits of the norm [JECFA 2002]. This is confirmed by the results of studies conducted by Grudzińska and Zgórska [2008], Żołnowski [2013] and Pobereżny et al. [2015].

According to Pobereżny et al. [2015] the consumption of 300 g of boiled potatoes does not exceed the permissible daily consumption of nitrates, so it does not raise concerns for the health of consumers. The average total per capita nitrate intake in Europe is 50 to 140 mg per day, and in the US, it is about 40 to 100 mg per day [Mensinga et al. 2003]. The use of organic fertilizers and basic mineral fertilization, according to Pobereżny et al. [2015], increases the consumption of nitrates, while potato biofortification with foliar micronutrient fertilizers, in our own research, reduced the amount of nitrates and nitrites in tubers, reducing their share in tuber fresh weight, and thus contributed to increasing the safety of food produced from potatoes. In the opinion of Shamloo et al. [2018] the use of cooking, steaming, and frying methods may also have a significant impact on the content of nitrates and nitrites in potatoes, and thus on human health.

In the conducted research, the highest content of nitrates and nitrites was found in the year with low rainfall. This is confirmed by the studies by Barbaś and Sawicka [2016] and Simson et al. [2016]. Grudzińska and Zgórska [2008] also add that mainly the air temperature and the sum of precipitation 10 days before harvesting determine the nitrate content in potato tubers. Fertilizers used for foliar application must first penetrate the leaf surface before entering the cytoplasm of the cell. This happens through the stomata, trichomes, hairs, or other specialized cuticle cells [Fernandez et al. 2013, Souza et al. 2020]. The absorption of nutrients by the leaves is influenced by the relative humidity and air temperature. At high humidity, plant cells are more hydrated, and salts deposited on the plant surface dry longer, which results in longer penetration of the leaves. Increasing the temperature range increases the solubility of the active ingredients and excipients, e.g., adjuvants, but at the same time the viscosity and surface tension are reduced. High air temperatures accelerate the evaporation rate of the substance and thus shorten the leaf penetration time [Fernandez et al. 2013]. The varied response of the studied cultivars caused by the micronutrient fertilizers application of foliar resulted from the diversity of the environment in which potato plants grew and developed, which may cause a modification of the internal regulation processes, both within the bush and in the field of the crop. The varied level of accumulation of nitrates in tubers of the studied cultivars as a result of applying micronutrient fertilizers could also be caused by a different chemical composition of the applied fertilizers.

It is estimated that about 65–75% of nitrates supplied from potatoes enter the body [Shamloo et al. 2018]. Given the growing population growth, the demand for food is increasing more and more. For this reason, the excessive and uncontrolled use of organic fertilizers has become common in many parts of the world to increase the production of this plant. Reduced consumption of soil fertilizers, and skillful, proper biofortification of potato plants with foliar microelement fertilizers can significantly reduce the content of nitrates in them. However, constant monitoring and control of the nitrate content in potato tubers is needed for the safety of consumers. In addition, more research is needed in this area, especially in the context of climate change.

CONCLUSIONS

1. Foliar fertilization with all combinations of multi-component and micronutrient fertilizers significantly reduced the content of nitrates and nitrites in potato tubers.
2. The cultivars tested determined the content of nitrates and nitrites in potato tubers. The early variety ‘Vineta’ accumulated the most of these unfavorable forms of nitrogen, and the late variety ‘Jelly’ the least.
3. The tested cultivars showed a diversified response to the use of multi-component foliar fertilizers, in the form of a decrease or increase in the content of nitrates in potato tubers. Only the very early ‘Viviana’ variety reacted by increasing the content of this form of nitrogen in tubers after applying the Fortis B Mo + Ferti Agro fertilizer complex.
4. Drought and high temperature during the potato vegetation period generated a higher content of nitrates and nitrites in potato tubers.

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