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REVIEW PAPER

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CULINARY QUALITY OF TUBERS OF SELECTED POTATO VARIETIES DEPENDING ON THE FOLIAR FERTILIZATION USED

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ABSTRACT

Background. The aim of this study was to determine the eating quality of tubers of selected potato cultivars depending on the foliar fertilization used.
Material and methods. The study was based on a 3-year (2013–2015) field experiment carried out in Haczów (49°40' N; 21°54' E), in brown, slightly acidic soil. The experiment was established with the randomized split-plot method, where the first-order factor was foliar fertilization with 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 a standard treatment, without foliar application. Second-order factors were 4 potato cultivars from different earliness groups (Agnes, Jelly, Viviana, Vineta).
Results. Foliar application of fertilizers has reduced tuber tendency of overcooking. The combination of fertilizers Fortis Duotop Zn Mn + Fortis Aminotop improved tuber palatability and tuber flesh structure, while their consistency was positively influenced by the application of fertilizers Fortis B Mo + Ferti Agro. The foliar fertilizers used did not affect the tuber mealiness of the studied cultivars. Varietal characteristics of potato tubers modified the culinary properties of potato. The cultivars Agnes and Viviana were characterized by the worst palatability, while the cultivar Jelly had the best taste and aroma. Under the dry summer conditions, of 2015 the tubers had the worse taste, the least delicate flesh and were the most susceptible to overcooking, while in the year with excess rainfall, they had the best taste and aroma, and their flesh was soft, delicate and the least prone to overcooking.
Conclusion. Varietal characteristics determined the palatability, flesh structure, tendency to overcook and consistency to a greater extent than the foliar application of foliar fertilizers containing macro- and micronutrients. Water shortage during the growing season contributed to a deterioration of the potato culinary characteristics, while, on the contrary, excess water contributed to their improvement.

Key words: consistency, cultivars, foliar fertilization, overcooking, potato, taste

INTRODUCTION

Potato producers can reduce the negative effects of the environment by using sustainable agriculture management strategies. In addition to choosing a cultivar, plant protection methods and continuous water supply, another cultivation factor in table potato production is the proper nutrient management. A sufficient supply of mineral nutrients can strengthen the potato plant against adverse growth conditions, is crucial for high yield and is essential in the production of table potato as they should meet high quality requirements (Trawczyński, 2019; Koch *et al.*, 2020). In addition to traditional practices of

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using minerals, foliar application of fertilizers can be an effective means to overcome unexpected shortages of macro-and micronutrients during plant growth (Qadri *et al.*, 2015; Jasim and Merhij, 2018). Plant growth is not controlled by the total amount of nutrients available, but by the amount of the rarest nutrients (Fernandez *et al.*, 2013; Trawczyński, 2015, 2019). This indicates the great importance of balanced nutrition for optimal plant growth. Foliar application of nutrients is an alternative way to provide them to plants in case of their absence or deficiency. It is done by spraying the leaves with a diluted solution of mineral salts or a chelate with the addition of a surface tension reducing agent (Fernandez *et al.*, 2013; Singh *et al.*, 2013; Trawczyński, 2015; Jasim and Merhij, 2018; Koch *et al.*, 2020). According to Fernandez *et al.* (2013), Singh *et al.* (2013) and Noaema (2018), foliar fertilization allows the grower to correct poor nutritional status of plants or to supplement deficiencies of some bioelements. It also enables the supply of nutrients during drought, intensive plant growth and development, and in situations where cultivation errors have been made. Nutrients are absorbed particularly intensively by young plant leaves (Fernandez *et al.*, 2013; Koch *et al.*, 2020). Older leaves are not able to transfer nutrients after ripening (Michałojć and Szewczuk, 2003; Fernandez *et al.*, 2013; Koch *et al.*, 2020). Producers offering table potato cultivars strive to meet the growing demands of the consumers. The leading position among consumer requirements is occupied by the culinary quality traits of tubers, as they pay attention to their taste, the features of the flesh structure and tendency of overcooking (Leszczyński, 2012; Zgórska, 2012; Kamiński, 2015; Naumann *et al.*, 2020). Potato palatability is a results of the combination of taste, aroma and texture. Palability determines the potato suitability for consumption and is associated with consistency, mealiness, moisture, texture and chemical composition. Aroma precursors synthesized by the plant are present in raw potatoes and consist mainly of sugars, amino acids, RNA and lipids (Jansky, 2010). Naumann *et al.* (2020) show that the eating quality traits of tubers are closely related and genetically controlled. Moreover, all these parameters are also related to the nutritional status of the plant and/or tubers. Important internal quality traits for potatoes are tuber flesh discolouration, dry matter, and starch content. External quality traits include tuber size and shape as well as resistance against mechanical stress during and after harvest. Deficiency or excess of essential nutrients during potato vegetation may, in fact, lead to internal quality disturbances (e.g. cause internal blotch – IBS). Combined with other stress conditions (impaired plant transposition), this leads to a loss of cell integrity (Naumann *et. al.*, 2020). An adequate and balanced nutrient supply of the potatoes is important for achieving not only high yields, but also the desired quality. The relationship between the nutrient supply and physiological processes that are important for potato tuber quality can be pointed out, such as the effect of potassium on photosynthesis and the reduction of darkening of the tuber flesh. In addition, the effect of a nutrient on a specific quality feature is superimposed on other factors, such as climate or specific local conditions. In addition to the relevant nutrients and their proportions, even the choice of fertiliser can be important. In addition to the principles of adequate potato fertilisation, other agronomic measures such as variety selection and plant protection should also be taken into account (Naumann *et. al.*, 2020). Also Wojdyła (2013) claims that nutrients, especially their excess, can negatively affect the taste and smell of tubers. An example of such a macronutrient is nitrogen.

Zimnoch-Guzowska and Flis (2006), in turn, showed that many potato traits are determined by genes that individually have a small effect. This applies to the content of starch, protein, reducing sugars, vitamin C and the darkening of the flesh of cooked tubers. However, the content of glycoalkaloids, anthocyanins and carotenoids as well as the darkening of raw tuber flesh is determined by the main genes accompanied by modifiers.

The literature on the subject lacks publications on the impact of foliar fertilizers on the culinary quality of potato tubers. Most literature references show the impact of nitrogen, phosphorus or potassium fertilization on the quality characteristics of potato tubers. Hence, the purpose of this work was to examine the effect of foliar fertilizers with a content of macro- and microelements used in the form of chelates on the culinary quality of tubers of selected potato varieties.

The alternative hypothesis was verified in the paper, which assumes that foliar fertilization has a beneficial effect on tuber consumption quality, against the null hypothesis that there are no differences between the objects on which foliar fertilization is applied.

MATERIAL AND METHODS

The research was based on a 3-year field experiment carried out in Haczów (49°40' N; 21°54' E), in brown, slightly acidic soil. The experiment was established with the randomized sub-block method in a split-plot design, where the first-order factors were foliar 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 treatment, without foliar fertilization (D). The second-order factors were table potato cultivars from different groups of earliness (Viviana – very early, Vineta – early, Agnes – semi-early and Jelly – semi-late). The starch content in the tested varieties was as follows: Viviana – 14.0%; Vineta – 14.5%, Agnes – 17.0 and Jelly – 16.0%.

Establishment of experiment

In autumn, fertilization with manure at a rate of 25 t·ha^{-1} and phosphorus-potassium fertilization at the rate of 44 kg P and 124 kg K·ha^{-1} was applied under the whole experiment. In spring, a single nitrogen fertilization dose in the form of urea was applied at the rate of 80 kg N·ha^{-1}. Seed planting material was planted between the 21st and 30th of April, at a spacing of 70 × 38 cm. Foliar fertilizers were used in accordance with the manufacturers' recommendations from the last ten days of May (phase BBCH 29) – until the beginning of fruit formation (phase BBCH 71). The tubers were harvested during technical maturity, depending on the cultivar: between the 21st and 31st of August (very early and early cultivars) and between the 11th and 20th of September (semi-early and semi-late cultivars). The characteristics of the applied foliar fertilizers are shown in Table 1.

Table 1. Characteristics of applied foliar fertilizers

Fertilizer name	Fertilizer composition	Application
Ferti Agro	nitrogen – 10%, phosphorus – 45%, potassium – 5%, boron – 0.05%, copper – 0.1%, iron – 0.05%, manganese – 0.1%, zinc – 0.4%, magnesium – 2%, sulphur – 8.0%, molybdenum – 0.01%, amino acids, vitamins	3 kg·ha^{-1}, four times every 7 days, starting from the development phase of the lateral shoots
Fortis Aminotop	9% organic nitrogen, amino acid, soluble, 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%, hydroxypoline – 0.77%, proline – 1.36%	2–3 dm^{3}·ha^{-1}, four times, from the moment when the plant reaches the height of 15-20 cm, every 10-15 days
Fortis B Mo	boron – 11%, molybdenum – 0.37%	1–1.5 dm^{3}·ha^{-1}, twice: the first dose in a period from formation of shoots to shortening of rows, the second dose – during the formation of tubers and inflorescences
Fortis Duotop Zn Mn	zinc – 7.1%, manganese – 5.1%, copper – 0.033%, boron – 0.024%, molybdenum – 0.003%, magnesium – 0.2%	2–3 dm^{3}·ha^{-1}, twice: in the phase of 10-15 cm plant growth and 15 days later

Soil sampling

Soil samples were collected in autumn after harvesting the previous crop with a soil stick, from the topsoil and from a depth of up to 20 cm. The total sample weighed 300–500 grams and was a mixture of approximately 20 primary samples (PN-R-04031: 1997). Chemical and physicochemical properties of the soil were determined in a certified laboratory of the District Chemical and Agricultural Station in Lublin (Scope of accreditation No AB 1186) by the following methods:

- soil granulometric composition was determined by laser diffraction (Bartmiński *et al.*, 2011; KQ/PB-75 version 04 from 26.03.2018),
- pH: 1 M KCl – electrometric (ISO 10390:2005),
- organic carbon content – Corg. – the Tiurin method (KQ/PB-34),
- content of absorbable forms of phosphorus and potassium – by the Egner-Riehm method (PN-R-04023:1996, PN-R-04024:1997, PN-R-04022: 1996 + AZ1:2002), and the content of available magnesium by the Schachtschabel method (PN-R-04020:1994 + AZ1:2004).

Tuber sampling

Tubers for testing were collected during harvest. Disease-free, undeformed and non-green tubers were selected. Approximately 60 medium-sized tubers (50–60 mm), characteristic for the given cultivars, were taken from the aggregate sample and intended for laboratory tests. The tubers were assessed in autumn, immediately after harvesting. Samples for evaluation were stored at 8–14°C and protected from light (Lenartowicz, 2013).

Tuber quality assessment

Assessment of the culinary quality of potato tubers was carried out at the Laboratory of the Stanisław Pigoń State Higher Vocational School in Krosno, based on the methodology adopted by the European Potato Research Association (EAPR) (Roztropowicz *et al.*, 1999).

A culinary evaluation of tubers, based on their colour, taste, odour and tendency to overcook, was carried out after cooking. The tubers were peeled as thinly and carefully as possible. After peeling and rinsing, the tubers were boiled in unsalted water until they were soft (about 20 minutes). First, the odour was evaluated, and then, after placing the tubers on a tray, each of the ten members of a commission, tested for sensory predispositions, according to PN-ISO (1998a, b), assessing the following characteristics: taste, colour, tendency of overcooking, pulp consistency, mealiness, structure of cooked flesh, on a 9° scale, in which 9° – the colour is unchanged, and 1° – the strongest darkening (Roztropowicz *et al.*, 1999). The pulp consistency was assessed based on the resistance of the boiled potato to mechanical pressure, the flouriness was determined on the basis of the tendency to scatter after cooking the tubers. The degree of surface overcooking was determined visually during cooking and immediately after cooking, taking into account the degree of cracking of the tuber surface, and the pulp structure was determined during consumption by grinding a portion of the tuber betweeen the tongue and the palate (Ratuszniak and Komorowska-Jędrys, 1995). All analyses were performed in triplicate for each combination of the field experiment.

Statistical calculation

The statistical analysis of the obtained results was based on the three-factor analysis of variance (ANOVA) model and multiple t-Tukey tests. The obtained study results were subjected to analysis of variance (ANOVA) and multiple t-Tukey tests, at the level of significance of $p_{0.05}$. In addition, coefficients of variation were calculated for the whole experiment. They are measures of random variability in the experiment (Laudański and Mańkowski, 2007). Statistical calculations were carried out using software Statistica 10.0 and Microsoft Excel 2007.

Meteorological conditions

Meteorological conditions in the years of the study were varied. The year 2013 was characterized by a dry summer, but very wet September, in 2014 there was an excess of rainfall in July, while 2015 was characterized by a significant rainfall shortage during the potato growing season (Fig. 1).

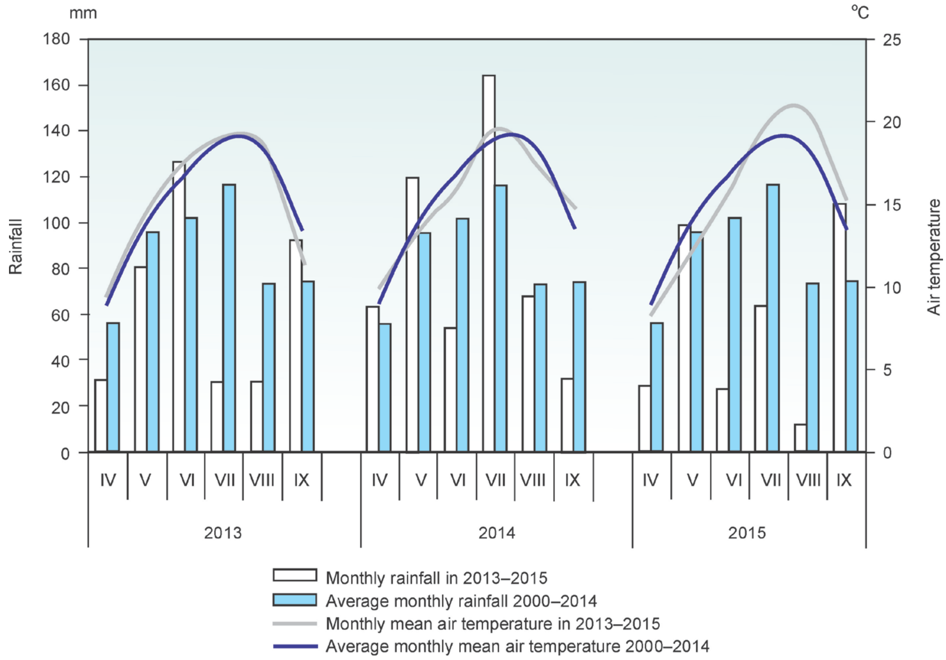

Fig. 1. Rainfall and air temperature during the potato growing seasons 2013–2015, against the average rainfall and air temperature between 2000–2014, according to data of the Hydrographic and Meteorological Station IMGW-PIB in Krosno

RESULTS

Soil analysis

The experiment was carried out in brown soil, formed of flysch sediments, with the mechanical composition of sandy clay, quality class IVb, the good rye complex, slightly acidic (5.69 pH in 1n KCl). The content of assimilable phosphorus and potassium in the studied soil was average, of magnesium – very high, and of copper, manganese, iron and zinc also average. The content of humus in the arable layer was high and averaged 2.66% (Nawrocki, 1991, Mocek *et al.*, 2015) (Table 2).

Table 2. Physical and chemical properties of soil (2013–2015)

Year	Content of assimilable macronutrients [mg·100 g^{-1} of soil]			$CaCO_3$ [%]	Humus [g·kg^{-1}]	pH [KCl]	Micronutrient content [mg·kg^{-1} of soil]			
	P	K	Mg				Cu	Mn	Zn	Fe
2013	5.49	16.6	19.7	0.02	2.71	5.66	5.6	175	14.3	1591.0
2014	5.23	16.6	19.5	0.02	2.55	5.70	5.9	174	14.5	1575.0
2015	5.45	16.8	19.9	0.01	2.72	5.70	5.3	175	14.4	1589.0
Mean	5.39	16.7	19.7	0.02	2.66	5.69	5.6	174.8	14.4	1585.0

Source: The Chemical and Agricultural Station in Lublin

Tuber taste and odour

The application of foliar fertilization significantly modified the taste of tubers. Tubers from the treatment where Fortis Duotop Zn Mn + Fortis Aminotop were applied were characterized by the highest palatability. Tubers from the experimental combination where foliar fertilization was not applied and from the treatments where Fortis Duotop Zn Mn + Fortis B Mo were applied had a significantly worse taste and were homogeneous in this respect. Tubers in the treatments fertilized with Fortis B Mo + Ferti Agro had the worst taste, compared to the standard treatment (Table 3).

Table 3. Impact of cultivars, fertilization and years of cultivation on the taste and odour of potato tubers

Experimental factors		Taste [scale 9°]	Odour [scale 9°]
Fertilization*	0	7.68b	8.10a
	A	7.84a	8.15a
	B	7.58c	8.35a
	C	7.75b	7.65b
	$HSD_{0.05}$	0.09	0.25
Cultivars	Agnes	7.38c	7.20d
	Jelly	8.42a	8.86a
	Viviana	7.43c	7.96c
	Vineta	7.63b	8.24b
	$HSD_{0.05}$	0.09	0.25
Years	2013	7.13c	7.76b
	2014	8.13a	8.21a
	2015	7.89b	8.21a
	$HSD_{0.05}$	0.07	0.20
Mean		7.71	8.06
RSD [%]		1.93	8.70

*0 – Standard treatment without foliar fertilization, A – Fortis Duotop Zn Mn + Fortis Aminotop, B – Fortis B Mo + Ferti Agro, C – Fortis Duotop Zn Mn + Fortis B Mo
RSD – relative standard deviation

The odour of cooked tubers was only worsened by fertilization with the following preparation: Fortis Duotop Zn Mn + Fortis B Mo (C), compared to the standard treatment without foliar fertilization (Table 3). The highest score in terms of taste and odour sensations was obtained by the cultivar Jelly, while the lowest – by Agnes. In terms of these traits the cultivar Vineta was the second, and Viviana the third (Table 3).

Meteorological conditions in the years of the study significantly modified the taste and smell sensations of the tubers. The most palatable tubers were obtained the in relatively humid and warm year 2014. In turn, in the very dry 2015, tubers with worse taste were collected, but in terms of odour they were homogeneous, compared to 2014. Tubers harvested in 2013, characterized by an extremely dry July and August, received the worst scores for the taste and odour sensations of cooked tubers (Table 3).

Other tuber flesh characteristics

Potato flesh was evaluated taking into account its consistency, structure, overcooking and mealiness (Table 4).

Foliar fertilization with Fortis Duotop Zn Mn + Fortis Aminotop (A) and Fortis B Mo + Ferti Agro (B) significantly affected obtaining a softer consistency of the cooked tubers compared to the standard combination without foliar fertilization (Table 4). Tubers from the treatment where foliar fertilization was applied with Fortis B Mo + Ferti Agro (B) turned out to be homogeneous in terms of the value of this trait, compared to tubers where Fortis Duotop Zn Mn + Fortis Aminotop (A) and Fortis Duotop Zn Mn + Fortis B Mo (C) were applied (Table 4).

The consistency of tuber flesh was determined to the greatest extent by the variety of the studied cultivar. Thus, the tuber flesh of the cultivar Agnes was the flouriest, while that of the cultivar Jelly was the most compact. The cultivar Vineta came in the second place, and Viviana – in the third place, according to the value of this trait (Table 4).

In 2013, characterized by drought in July and August, tubers with the most compact flesh were obtained. A flourier consistency of tuber flesh was observed in 2014, where excess rainfall was noted, and in 2015, when a significant rainfall deficiency was noted during the potato growing season (Table 4).

All factors of the experiment affected the structure of tuber flesh. A significant difference in the value of this trait was found only between the treatments with foliar fertilization with the preparations: Fortis Duotop Zn Mn + Fortis Aminotop (A) and Fortis Duotop Zn Mn + Fortis B Mo (C), in favour of the latter. The first combination of fertilizers reduced the delicacy of tuber flesh. The remaining combinations of fertilizers proved to be homogeneous in terms of this characteristic (Table 4).

Table 4. Impact of fertilization, cultivar and year of cultivation on the characteristics of potato tuber flesh [9° scale]

Experimental factors		Consistency	Flesh structure	Overcooking	Mealiness
Fertilization*	0	5.63c	5.06a,b	5.81a	4.43a
	A	6.19a	4.88b	5.63b	4.50a
	B	6.12a,b	5.13a,b	5.63b	4.57a
	C	5.81b,c	5.38a	5.45c	4.50a
	HSD $_{0.05}$	0.36	0.43	0.18	ns**
Cultivars	Agnes	8.01a	6.75a	8.06a	7.31a
	Jelly	4.50d	3.76c	2.99d	2.88d
	Viviana	6.19b	5.00b	6.75b	4.12b
	Vineta	5.06c	4.93b	4.68c	3.69c
	HSD $_{0.05}$	0.36	0.43	0.18	ns**
Years	2013	5.49b	5.63a	6.19a	4.46a
	2014	6.05a	4.50c	5.06c	4.50a
	2015	6.28a	5.20b	5.63b	4.55a
	HSD $_{0.05}$	0.27	0.34	0.14	ns**
Mean		5.94	5.11	5.63	4.50
RSD [%]		12.96	16.67	8.43	16.75

*0 – Standard treatment without foliar fertilization, A – Fortis Duotop Zn Mn + Fortis Aminotop, B – Fortis B Mo + Ferti Agro, C – Fortis Duotop Zn Mn + Fortis B Mo,
** non-significant at $p_{0.05}$
RSD – relative standard deviation

The studied cultivars had a significant effect on the structure of the tuber flesh. The cultivar Jelly was characterized by the most delicate flesh, while the cultivar Agnes by the least. Viviana and Vineta turned out to be homogeneous in terms of this trait (Table 4). After the humid and warm growing period of 2014, the tubers were characterized by the most delicate flesh, while the least delicate were – in 2013, when July and August were very dry, and June and September were characterized by excess rainfall (Table 4).

The degree of overcooking the flesh is an assessment of the tendency of overcooking and cracking when cooking tubers. All foliar fertilizers reduced the tendency to overcook tubers when, compared to the standard treatment without applying foliar fertilizers (Table 4). Tubers with the least cracked surface after cooking were observed after the application of Fortis

Duotop Zn Mn + Fortis B Mo (C). Fertilizers in treatments A and B turned out to be homogeneous in terms of the value of this trait (Table 4).

The cultivar Agnes, followed by Viviana and Vineta, had the highest tendency to have overcooked tubers. Tubers of the cultivar Jelly had the least cracked surface after cooking (Table 4).

Tubers harvested in the warm and humid 2014 were the least susceptible to overcooking, while tubers harvested in 2013, when July and August were very dry, were most susceptible to overcooking (Table 4).

Mealiness indicates the tendency of cooked tubers to crumble. The foliar fertilizers applied or the meteorological conditions in the years of the study did not have a significant influence on the value of this characteristic (Table 4). The genetic properties of the studied cultivars were the most decisive for the mealiness of the tuber flesh. In terms of the value of this characteristic, the studied cultivars can be ranked as follows: Agnes > Viviana > Vineta > Jelly; where Agnes was distinguished by floury to very floury flesh, and Jelly - slightly floury and slightly sparkling (Table 4).

DISCUSSION

In potato production the term "quality" is a multi-faceted feature that is largely determined by the use of the final product. In the case of potatoes used for consumption, the most important quality parameters are taste, odour, consistency, flesh structure, and tendency of overcooking (Leszczyński, 2012; Gerendás and Führs, 2013; Grudzińska *et al.*, 2016; Krochmal-Marczak *et al.*, 2016; Bienia *et al.*, 2019). Potato palatability is one of the basic factors determining its quality (Wojdyła, 2013; Naumann *et al.*, 2020). This is a complex trait which is better described by the term "taste", which includes a flavour that is dependent on solid ingredients and an odour associated with volatile substances as well as the texture of the tuber. Palatability depends on the metabolic and chemical processes of tubers that occur during the growth and storage, and especially during boiling, frying or baking, and on the consumer's perception, i.e. human physiology and psychology. The perceived taste of food depends not only on the taste receptors, but also on the olfactory receptors. People have 5 types of taste receptors that correspond to important groups of chemicals in food and they feel the taste: sweet, salty, bitter, sour and "umami" (from Japanese "delicious") (Kamiński, 2015). According to Jansky (2010), excessive nitrogen fertilization usually worsens the taste perception, because it probably promotes the formation of amides and amines, that spoil taste and are unpleasant--smelling. Wojdyła (2013) also observed such a phenomenon using higher rates of nitrogen and potassium when he noted that tuber taste was improved when magnesium was used. Płaza and Makarewicz (2014) showed that potato tubers fertilized with white melilot ploughed in autumn or left in the form of mulch until spring had better taste compared to tubers fertilized with manure. In the present study, tubers from the treatments where Fortis Duotop Zn Mn + Fortis Aminotop (A), i.e. fertilizers containing zinc, manganese and organic nitrogen of amino acid composition, were applied had the highest palatability. Amino acids affect the mechanism of stimulating plant development, while microelements are designed to nourish plants. Amino acid preparations do not nourish plants in a direct way, but their action is based on stimulation of individual physiological processes in the plant, and, therefore, their importance and role in the growth and development of plants is important. By supplying the plant with amino acids from the outside, it does not have to waste energy on their production. Thanks to this, energy can be used for faster and better plant development. This allows for an increase in plant performance and improved quality (Gouda *et al.*, 2015). Kowalczyk and Zielony (2008) found that amino acids, a well-known biostimulant, have a positive effect on plant growth and yield and significantly alleviates injuries caused by abiotic stress. This was confirmed by El-Zohiri and Asfour (2009) on potato, that had had foliar applied amino acids.

Zinc is a cofactor for over 300 enzymes and proteins and has an impact on cell division, nucleic acid metabolism and protein synthesis (Marschner, 2012). Zinc promotes biosynthesis of growth hormones and the formation and production of starch and seeds (Marschner, 2012). In addition, Mousavi *et al.* (2007) reported that foliar application of zinc improved all plant characteristics related to crop and potato crop quality. In the research of Ahmed *et al.* (2011) foliar application of zinc increased the content of starch, nitrogen, potassium and zinc in potato tubers. They also found that due to the metabolic role of zinc in protein synthesis, enzyme activation and carbohydrate metabolism, the use of fertilizers containing this element increases the quality and quantitative efficiency of potato tubers (Ahmed *et al.*, 2011).

In addition to zinc and manganese the, Fortis Duotop ZnMn fertilizer also contains copper, boron, molybdenum and magnesium. These microelements take part in many biochemical processes in plans that condition the proper course of, among others, enzymatic reactions.

According to Wojdyła (2013), an increase in nitrogen fertilization increases the total protein content, while potassium increases the hydration of the cytoplasm. Potassium fertilization increases the delicacy, reduces the tendency of overcooking and increases the firmness of the tuber flesh, which means that the tubers are then more delicate and less floury. The use of higher doses of magnesium causes a greater tendency of overcooking, a softer texture, the flesh is floury, dry and has a rough structure (Wojdyła, 2013). According to Wojdyła (2013), tubers with a higher starch content have a higher palatability.

In the conducted experiments, the most beneficial effect of foliar fertilization on the flesh structure was obtained by applying Fortis Duotop Zn Mn + Fortis B Mo. Seling *et al.* (2000) has shown that calcium (Ca) is primarily involved in various functions of the plant cell that are related to the quality of potato traits, such as maintaining structural cell integrity or regulating metabolic responses. This element is needed to stabilize the cell wall and membrane (Palta, 2010). In cell walls, Ca contributes to their characteristic structure by bridging pectin galacturonates through carboxylate groups (Subramanian *et al.*, 2011). Nauman *et al.* (2020) claim that membrane stabilization is caused by bridging phosphate and carboxylate groups of phospholipids and proteins on membrane surfaces. Based on these functions of cell wall and membrane stability, it can be expected that Ca is necessary to establish and maintain the firmness of potato peel (Koch *et al.*, 2019). However, potato tubers usually have a very low Ca content, which can be attributed to the fact that Ca is mainly transported by xylem (Palta, 2010; Koch *et al.*, 2019). Calcium deficiency can lead to many physiological disorders of plants, such as internal brown spot (IBS) or hollow heart, which can also lead to a decrease in the quality of the interior of potato tubers. An additional Ca supply may increase tuber Ca levels and reduce IBS (Koch *et al.*, 2019). Palta (2010) showed that Ca concentration in tubers could increase if Ca was directly applied in the tuber-stolon area. Zgórska and Grudzińska (2012) have shown that the flesh structure is closely related to the dry matter and starch content in potato tubers. Tubers containing less dry matter and starch are of the salad type, while those containing more of these components are of the medium-firm or mealy type. To high a starch content worsens the degree of overcooking because the starch swells and causes damage to cellular structures (Thybo *et al.*, 2006). According to Naumann *et al.* (2020), the impact of nutrient supply on the quality of potato tubers initially depends on their physiological functions, but the relationship to other nutritional needs should also be considered.

The taste and odour are very important characteristics of table potatoes and those intended for food processing. According to Jansky (2010) and Leszczyński (2012), precursors of chemical compounds that determine the taste of potato are sugars, amino acids, fats, glycoalkaloids and nucleotides, while starch does not determine the taste of tubers. According to Bártová *et al.* (2013); Lombardo *et al.* (2013); Brazinskiene *et al.* (2014); Grudzińska *et al.* (2016), the taste and odour of potato tubers is affected by the supply and availability of both macro- and micronutrients. However, many other factors, such as cultivar, soil and climatic conditions, overlap with the effects of nutrients on these traits. In the present study, the taste and odour of tubers turned out to be traits significantly associated with the cultivar. This is also confirmed by the results of studies by numerous authors (Wojdyła, 2013; Żołnowski, 2013; Kamiński, 2015; Krochmal-Marczak *et al.*, 2016; Naumann *et al.*, 2020). The study by Grudzińska *et al.* (2016) indicates that the taste and odour of tubers depend only on the cultivar. Zarzecka *et al.* (2017), in turn, says that not varietal characteristics, but herbicides used to control weeds have the greatest effect on palatability. Excess sugars and ash worsen the taste, while on the other hand free amino acids, nucleotides and vitamin C improve the taste. Glycoalkaloids adversely affect this property and cause a bitter taste (Amer *et al.*, 2014).

Varietal diversity of important culinary traits, such as the consistency or structure of cooked potato tuber flesh, is shown in the studies by Bárta and Diviš (2006), Wojdyła (2013) and Żołnowski (2013). Wroniak (2007) shows that the consistency of cooked tuber flesh depends only on the content of starch in tubers. Voronov *et al.* (2019) also claim that the culinary qualities of potatoes depend on the size of starch grains; the larger they are, the greater the solubility and viscosity of the starch. Voronov *et al.* (2019), studying the culinary qualities of seven cultivars grown in Russia, obtained the best scores only for the cultivar Crystel, while the others were rated as good. According to Kamiński (2015), the genetic background of the culinary traits most important for consumers, such as tuber taste and texture, is still unknown. He says that this is due to their complexity and lack of differentiators that would allow them to be better and more accurately defined. Bárta and Diviš (2006) and Żołnowski (2013) indicate a relationship between the flesh structure and the genotype, however, this was not confirmed in the study by Wojdyła (2013). Grudzińska *et al.* (2016) showed that the cultivar and processing of potato tubers during storage have a significant impact on the structure of cooked potato tubers. Seefeldt *et al.* (2011) found that changes in the texture of potatoes after cooking are associated with the physicochemical properties and the cell wall structure. The texture of cooked tubers depends on the cooking conditions and other factors (starch degradation, pectin degradation, cell wall disruption, cell separation, swelling and gelation of starch, etc. (Nourian *et al.*, 2003; Grudzińska *et al.*, 2016). In the study by Yang *et al.* (2015), texture properties were indirectly affected by the temperature and cooking time of potato tubers, there were also differences in the structure of the flesh between cultivars. This shows the influence of genetic characteristics on the culinary properties of tubers. Starch content plays a significant role in shaping the overcooking of potato tubers as too high a content worsens the degree of overcooking, because the starch swells and causes damage to cellular structures (Thybo *et al.*, 2006). The tendency to overcook the pulp surface is related to the saturation of cell walls with pectin substances (protopectin and water-soluble pectin), as in the cell walls of plant tissue the fraction of pectin substances forming the central plaque plays a stiffening and strengthening role (Grudzińska *et al.*, 2016). The texture-forming properties of pectins are a result of their mainly ability to form "calcium bridges" between pectin carboxylic groups and Ca^+ and Mg^+ ions. Calcium ions at the junction of adjacent pectin molecules give the tissue a more stable and firm structure thus preventing dissolution of pectins contained in cell walls and in the middle plate. Pectins with a lower degree of esterification and a higher content of bivalent ions particularly contribute to this process. From among the group of pectin compounds, the protopectin fraction, which performs cementing and stiffening functions in the central plate and has a special ability to bind calcium ions, deserves attention (Pińkowska and Złocińska, 2014).

The mealiness or fatiness of boiled potatoes is often associated with swelling and gelatinization of starch and the strength of pectin compounds (Grudzińska *et al.*, 2016). Bordoloi *et al.* (2012) also has shown that the sensory features of tubers are related to the starch content and that a higher starch content means that the tubers are mealier, crack faster during cooking, and the cooking time is shorter compared to tubers with a lower starch content.

The flavour and odour sensations of tubers were also modified by the meteorological conditions in the present study. The best tubers in terms of taste and odour were obtained in 2014, characterized by excess rainfall in July, when there was the largest accumulation of dry matter and starch in the tubers. According to many authors (Wojdyła, 2013; Żołnowski, 2013; Kamiński, 2015), their palatability is significantly modified by the meteorological conditions during the potato growing season. Rymuza *et al.* (2015) obtained their tastiest tubers in a fairly dry year.

According to Płaza (2010), tubers harvested in dry and hot years are more prone to overcooking and have a floury consistency, they are also mealier, and their flesh is dry and rough. This confirms the results obtained in the present study regarding the consistency and overcooking of tuber flesh. According to Wojdyła (2013), floury consistency related to the accumulation in the tubers of more dry matter, starch and total sugars, that affects the overcooking of tubers. Bárta and Diviš (2006) and Naumann *et al.* (2020), however, do not confirm such a relationship. Also, Escuredo *et al.* (2018) found no effect of meteorological conditions on the texture of tubers.

CONCLUSIONS

1. Foliar application of fertilizers reduced the tendency of tubers to overcook. The combination of fertilizers Fortis Duotop Zn Mn + Fortis Aminotop (A) improved tuber palatability and tuber structure, while the flesh consistency was positively affected by the application of fertilizers Fortis B Mo + Ferti Agro (B). The foliar fertilizers used did not affect the mealiness of tuber flesh of the studied cultivars.
2. Varietal traits of potato tubers modified the culinary properties of potato. The cultivar Jelly had the best taste and odour, the most compact and delicate flesh, and was the least mealy and the least susceptible to overcooking, while Agnes and Viviana were characterized by the worst palatability and its flesh was the most floury, rough, mealy and prone to overcooking.
3. Weather conditions significantly determined the culinary quality of the tubers. In dry summer conditions, the tubers had poorer palatability, the least delicate flesh, and were most susceptible to overcooking, while in the year with excess rainfall in July, they had the best taste and odour, and their flesh was soft, delicate and least prone to overcooking.

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JAKOŚĆ KONSUMPCYJNA BULW WYBRANYCH ODMIAN ZIEMNIAKA W ZALEŻNOŚCI OD STOSOWANIA NAWOŻENIA DOLISTNEGO

Streszczenie

Celem badań było określenie jakości konsumpcyjnej bulw wybranych odmian ziemniaka w zależności od stosowanego nawożenia dolistnego. Badania oparto na 3-letnim (2013–2015) doświadczeniu polowym przeprowadzonym w Haczowie (49°40' N; 21°54' E), na glebie brunatnej, lekko kwaśnej. Eksperyment założono metodą losowanych podbloków, gdzie czynnikiem I rzędu było nawożenie dolistne następującymi nawozami: Fortis Duotop Zn Mn + Fortis Aminotop (A), Fortis B Mo + Ferti Agro (B), Fortis Duotop Zn Mn + Fortis B Mo (C) i obiekt standardowy, bez nawożenia dolistnego. Czynnikiem II rzędu były 4 odmiany ziemniaka z różnych grup wczesności (Agnes, Jelly, Viviana, Vineta). Aplikacja dolistna nawozów przyczyniła się do zmniejszenia skłonności bulw do rozgotowywania. Kombinacja nawozów Fortis Duotop Zn Mn + Fortis Aminotop wpływała na poprawę smakowitości bulw oraz strukturę miąższu bulw, zaś na ich konsystencję oddziaływała korzystnie aplikacja nawozów Fortis B Mo + Ferti Agro. Stosowane nawozy dolistne nie wpływały na mączystość miąższu bulw badanych odmian. Cechy odmianowe bulw ziemniaka modyfikowały właściwości kulinarne ziemniaka. Najgorszą smakowitością odznaczały się odmiany Agnes i Viviana zaś odmiana Jelly odznaczała się najlepszym smakiem i zapachem. W warunkach suchego lata bulwy miały gorszą smakowitość, najmniej delikatny miąższ i były w największym stopniu podatne na rozgotowywanie, zaś w roku z nadmiarem opadów charakteryzowały się najlepszym smakiem i zapachem, a ich miąższ był miękki, delikatny i najmniej skłonny do rozgotowania. Cechy odmianowe decydowały w większym stopniu o smakowitości, strukturze miąższu, skłonności do rozgotowywania i konsystencji niż stosowanie nawozów dolistnych z zawartością makro- i mikroelementów. Niedobór wody w okresie wegetacji przyczynił się do pogorszenia cech kulinarnych ziemniaka, zaś ich nadmiar odwrotnie – do ich poprawy.

Słowa kluczowe: konsystencja, nawożenie dolistne, odmiany, rozgotowywanie, smak, ziemniak