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ORIGINAL PAPER

The effect of nitrogen-fixing microbiological preparation on the yield and selected features of potato tubers*

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Abstract

As a result of a 2-year field study on light soil, the effect of foliar application of microbiological preparation BlueN® on the yield and content of selected features of potato tubers was determined. The microbiological preparation used in the experiments at a dose of 333 g ha^{-1} contained *Methylobacterium symbioticum* bacteria with nitrogen-fixing properties. The experimental factors were: potato varieties (Hermes, Tajfun), objects (control object – where no of microbiological preparation BlueN®, was used, object were BlueN® was used), doses of mineral nitrogen (basic dose – 100 kg ha^{-1}, dose reduced by 30% – 70 kg ha^{-1}). The studies assessed the level of total tuber yield and the content in tubers of dry matter, starch, vitamin C, nitrates, total nitrogen, and the uptake of this component with the tuber yield. The highest increase in tuber yield in the object where microbiological preparation was used was recorded after the application of a nitrogen dose of 70 kg ha^{-1} to the Tajfun variety. After the application of the microbiological preparation in the object, the tuber yield was higher by 6.1% compared to the control object, where no microbiological preparation was used. The BlueN® significantly reduced the content of nitrates, increased dry matter and total nitrogen in tubers and the uptake of this component with the yield as compared to the control object. Based on the yield of tubers, it was demonstrated that the use of microbiological preparation BlueN® allowed for the reduction of the dose of mineral nitrogen by about 30 kg ha^{-1}.

Keywords: nitrogen, nitrogen-fixing bacteria, tuber quality, yield, potato

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INTRODUCTION

One of the main factors influencing the level of yield and quality of potato tubers is fertilization (Ciećko et al. 2010, Żołnowski 2010, Martirosyan et al. 2024). To maintain potato yield and tuber quality at a high level and to achieve high production efficiency, it is necessary to strive for specific solutions that will make it possible to reduce fertilization costs. The most strategic component here is nitrogen and specific savings should be looked for in this area (Fontes et al. 2010, Kumar et al. 2017, Ierna and Mauromicale 2019). On the one hand, high prices of mineral fertilizers, including nitrogen fertilizers, and on the other hand, limited availability of this component from the soil resulting from periods of drought and high temperatures during vegetation, among others, should encourage alternative methods of their use (Preininger et al. 2018, Grzyb et al. 2021). Future activities must also take into account pro-ecological solutions in line with the European Green Deal (Guyomard et al. 2023, Jarosz 2023). A solution may be the use of microbiological preparations, which in terms of plant nutrition enable the supply of nitrogen to plants from the air, both in the process of symbiosis through the root system, as well as non-symbiotically through the leaves (Ardanov et al. 2011, Gałązka and Podleśny 2024, Woźniak and Gałązka 2019). In relation to increasing nitrogen resources for plants through the root system, bacterial vaccines are used and legumes are introduced into cultivation (Soumare et al. 2020). Another way to provide nitrogen nutrition in connection with the action of microorganisms may be the supply of various species of non-hemispheric plants, including potatoes, with an additional amount of assimilable nitrogen absorbed by the leaves from the air. It seems that the fixation of specific amounts of nitrogen from the air can occur after the application of foliar preparations containing specific bacteria capable of colonizing the aerial parts of plants. Thanks to foliar application, the preparation can penetrate through open stomata, and nitrogen assimilation takes place through the action of nitrogenase (Buren and Rubio 2018). An example of this is the microbiological preparation BlueN®, containing the *Methylobacterium symbioticum* strain of bacteria (Corteva 2024).

The aim of this study was to determine the effect of a foliar preparation that fixes nitrogen from the air on the yield and content of selected components and the uptake of total nitrogen by potato tubers.

MATERIAL AND METHODS

Field experiments were conducted in years of 2022-2023 at the Plant Breeding and Acclimatization Institute - National Research Institute, Jadwisin Branch (52°28′06.23″N 21°02′43.33″E) on arable light soil classified as belonging to soils with clay translocation, type Luvisols, subtype Stagnatic Luvisols, with the particle size composition of loamy sand (IUSS Working Group WRB 2015). A 3-factor experiment was established in a randomized subblock design in three replications. The experiment factors were varieties (I): the Hermes variety (chips, medium early, Agrico Polska sp. z o.o., the Netherlands) and the Tajfun variety (edible, medium early, Pomorsko-Mazurska Hodowla Ziemniaka sp. z o.o., Poland); objects (II): control object, where no BlueN® no was used, and the object where BlueN® was used; nitrogen doses (III): 100 kg ha^{-1}, 70 kg ha^{-1}.

Organic fertilization consisted of shredded straw ploughed in immediately after harvesting winter triticale at a dose of 5 t ha^{-1} and a white mustard catch crop ploughed in the autumn at a dose of 15-16 t ha^{-1}. Mineral fertilization with phosphorus and potassium was applied in early spring at a dose of 26.2 kg P ha^{-1} (triple superphosphate – 17.4% P) and 99.6 kg K ha^{-1} (potassium sulphate – 41.5% K). Mineral fertilization with nitrogen at a basic dose of 100 kg N ha^{-1} and reduced by 30% - 70 kg N ha^{-1} was applied a single time in the spring before planting the tubers in the form of ammonium nitrate (nitro-chalk – 27% N). A microbiological preparation BlueN® (Corteva Agriscience, Indianapolis, IN, USA) containing *Methylobacterium symbioticum* SB0023/3 T bacteria at a concentration 3 x 10^7 CFU g^{-1} was applied by foliar spray to potato plants in the BBCH 35 phase (second ten days of June) at a dose of 333 g ha^{-1} after dissolving in 300 dm^3 ha^{-1} of water. Each year, these treatments were performed in the afternoon at an air temperature of approximately 15°C and humidity of approximately 87%. Weeds were controlled mechanically using a spreader twice before the emergence of potato plants, and chemically by using one herbicide before emergence: Proman 500 SC (metobromuron) at a dose of 4 l ha^{-1}, and another one after the emergence of potato plants: Titus 25 WG (rimsulfuron) at a dose of 60 g ha^{-1} + Trend 90 EC at a dose of 0.1 l ha^{-1} (BBCH 15). Each year, potato blight control treatments were applied four times during the growing season. During the plant growing period, preparations against the potato beetle were used three times.. The soil in the years of the study was characterized by acidic reaction, high content of available phosphorus, medium content of mineral nitrogen, potassium and low organic carbon, and magnesium content (Table 1).

Table 1

Soil chemical properties (layer of 0-20 cm) before starting the experiment

Years	pH_{KCl}	N mineral	C organic	P	K	Mg
		(kg ha^{-1})	(%)	(mg kg^{-1})		
2022	5.5	45	0.55	84.0	87.0	30.0
2023	5.3	50	0.50	86.0	116.0	25.0

Weather conditions in the study years were determined based on precipitation totals and average air temperatures compared to multi-year averages and the Selyaninov hydrothermal coefficient. In 2022, precipitation deficits were recorded in April, May, and June. April was quite cool, and May was moderately warm. In July, precipitation levels were above the multi-year total. In turn, August saw a significant precipitation deficit. June, July, and August were warm. In September, precipitation totals were close to the multi-year total and it was cool. Based on the Selyaninov coefficient, the year 2022 was considered moderately dry. In 2023, April saw sufficient precipitation and it was moderately warm. In May, precipitation deficits were recorded, and the air temperature did not differ from the multi-year average. In June and July, precipitation deficits persisted, and the average air temperature was higher than the multi-year average. In August, excess precipitation was recorded and air temperatures were significantly higher than the multi-year average. September, in turn, was characterized by a shortage of precipitation and significantly higher air temperatures than the multi-year average. Based on the Selyaninov coefficient, 2023 was a dry year (Table 2).

Table 2

Weather conditions in the investigation years (the meteorological station in Jadwisin)

Year	Month						
	April	May	June	July	August	September	Sum/Mean
Sum of rainfalls (mm)							
2022	34.1	35.9	66.0	107.3	25.0	50.0	318.3
2023	41.2	36.2	34.1	52.1	78.8	13.2	255.6
2000-2021	37.0	56.0	75.0	76.0	60.0	48.0	352.0
Mean air temperature (°C)							
2022	6.9	13.6	19.3	19.2	21.8	12.0	15.5
2023	8.8	13.6	18.4	20.2	20.9	18.2	16.7
2000-2021	7.9	13.6	16.5	18.5	17.9	13.1	14.6
Selyaninov's hydrothermal coefficients (k)*							
2022	1.65	0.88	1.14	1.86	0.38	1.39	1.22
2023	1.55	0.86	0.64	0.83	1.22	0.24	0.89

* The value of the Selyaninov coefficient (Skowera 2014): extremely dry $k \leq 0.4$, very dry $0.4 < k \leq 0.7$, dry $0.7 < k \leq 1.0$, moderately dry $1.0 < k \leq 1.3$, optimal $1.3 < k \leq 1.6$, moderately humid $1.6 < k \leq 2.0$, humid $2.0 < k \leq 2.5$, very humid $2.5 < k \leq 3.0$, extremely humid $k > 3.0$

Potatoes were planted in the last ten days of April, in the spacing of 75 x 33 cm. Harvest was carried out in the last ten days decade of September. The plot size was 14.85 m^2, and the number of plants per plot was 60. During harvest, the total yield of tubers from each plot was assessed and tubers were sampled to determine the content of components. Dry matter content was determined by a 2-stage drying method, at temp. of 60 and 105°C. Starch content was determined by the Evers polarimetric method

(PN-EN ISO 10520 2002). Starch hydrolysis was carried out in a boiling water bath, and then the protein was precipitated using phosphoric-tungstic acid. The starch content was determined using an automatic Polamat S polarimeter (Carl Zeiss, Jena, Germany). The vitamin C content was determined as the sum of L-ascorbic acid and dehydroascorbic acid using the Tillmans method, by titration with a solution of 2.6-dichlorophenolindophenol (Rutkowska 1981). The NO_3^- (V) nitrate content was determined reflectometrically using Merckoquant nitrate ion test strips and an RQflex® Merck measuring device (Merck KGaA, Darmstadt, Germany). In the presence of acidic buffer, nitrate ions react with an aromatic amine to form a diazonium salt, which, in reaction with N-(1-naphthyl)ethylenediamine, forms a red-violet dye. The concentration of this dye is determined reflectometrically (Merck 2023). The total nitrogen content in dry matter was determined by the Kjeldahl method using a Kjeltec 2200 Foss automatic distiller (FOSS Polska, Warsaw, Poland). Nitrogen uptake was determined based on the N-total content in tubers and the dry mass yield of tubers.

The research results were statistically processed using the Statistica 13.3 program and the ANOVA analysis of variance. The analysis of variance concerning the potato yield and studied features (dependent variables) was related to the varieties, objects, doses and years (independent variables). The analysis consisting of a comparison of means was performed using the Tukey test at the level of p=0.05 (TIBCO Statistica 2017).

RESULTS AND DISCUSSION

Tuber yield

The effect of the microbiological preparation on the yield of potato tubers varied depending on the applied dose of mineral nitrogen and the varieties tested in the study years (Table 3).

Table 3

The influence interaction of the studied factors on the tuber yield

Year	Variety	Without BlueN®		BlueN®		Mean
		100 kg N ha^{-1}	70 kg N ha^{-1}	100 kg N ha^{-1}	70 kg N ha^{-1}	
Tubers yield (t ha^{1})						
2022	Hermes	51.76 *cd*	49.36 *de*	53.04 *cd*	52.18 *cd*	51.58 *B*
	Tajfun	63.77 *a*	56.74 *bc*	66.71 *a*	63.20 *ab*	62.60 *A*
2023	Hermes	42.89 *efg*	41.23 *fg*	44.10 *ef*	43.18 *ef*	42.85 *C*
	Tajfun	33.98 *h*	29.69 *h*	36.18 *gh*	32.83 *h*	33.17 *D*
Mean		48.10 *A*	44.25 *B*	50.01 *A*	47.85 *A*	

a, *b* (for interaction years × variety × object × dose of nitrogen); *A*, *B*, *C* (for average values); mean values indicated by the same letters are not statistically significantly different at the 0.05 level according to the Tukey's test

In a moderately dry year, a higher tuber yield and its growth under the influence of BlueN® was achieved by the Tajfun variety than by the Hermes variety. The tuber yield of the varieties did not differ significantly between the objects in which the nitrogen dose of 100 kg ha^{-1} was applied, although it was higher in the object with BlueN®. At a lower nitrogen dose of 70 kg ha^{-1}, significant differences were shown in favor of the object with BlueN® application, which on average was higher by 5.7% in the case of the Hermes variety and by 11.4% for the Tajfun variety. Concerning the Hermes variety, after the application of the dose of 70 kg N ha^{-1} in the object with BlueN®, a higher tuber yield was obtained than after the application of a dose of 100 kg N ha^{-1} without BlueN®. In a dry year, a significantly higher yield of tubers was obtained from the Hermes variety than from the Tajfun variety, which could indicate a greater tolerance of the former variety to stress related to water deficiency. Similarly to the moderately dry year, a greater increase in tuber yield was achieved by the Tajfun variety after the application of BlueN®, both with the basic nitrogen dose and the one reduced by 30%. After the application of the dose of 100 kg N ha^{-1} in the object with BlueN®, an increase in tuber yield was 2.8 and 6.5% for the Hermes and Tajfun varieties, respectively, while with the application the dose of 70 kg N ha^{-1}, it was 4.7 and 10.5%, respectively. Similarly to the moderately dry year, in the Hermes variety, after the application of the dose of 70 kg N ha^{-1} in the object with BlueN®, the tuber yield was higher in comparison to the combination with the dose of 100 kg N ha-1 without BlueN® (Table 4). In the studies conducted at the University of Life Sciences in Poznań, it was found that the use of BlueN® replaced the nitrogen dose of 50 kg ha^{-1} for potatoes. Mohammed et al. (2014),, using bacterial preparations on desert soils obtained about 50% coverage of potato plants for nitrogen, and foliar application of bacterial inoculants was expressed by an increase in tuber yield by about 25% compared to the control object. The study by Volkogon et al. (2021) showed an increase in potato yield owing to the use of a microbiological preparation containing *Azospirillum brasilense 410* bacteria, especially as a supplement to a reduced level of nitrogen fertilization. The application of *Azospirillum brasilense* increased tuber yield by 42.4% at a nitrogen dose of 40 kg ha^{-1} and by 116.9% as compared to 80 kg N ha^{-1} and the control object (Volkogon et al. 2021). The effectiveness of foliar application of microbiological preparations fixing nitrogen from the air varied depending on the plant species and had different effects on the yield. In rapeseed, a beneficial effect of foliar application of nitrogen-fixing bacteria *Azotobacter chroococcum* strain 5 and *Azospirillum lipoferum* strain 21, and especially their mixture, on seed yield was obtained (Ahmadi-Rad et al. 2016). With respect to lettuce, a limited effect of foliar application of bacterial vaccine *Methylobacterium symbioticum* on leaf yield was demonstrated (Arrobas et al. 2024). In maize, a better yield effect from 5.5 to 13.4% was demonstrated after soil application of bacterial strains *Azotobacter chroococum*, *Bacillus subtitis*, *Bacillus megatherium* and their mixtures, while foliar treatments with preparations based on these microorganisms did not show a positive effect on maize grain yield compared to the control object (Efthimiadou et al. 2020). In another study on maize, a positive effect of the increase in the dry mass of the crop was obtained after foliar application of the bacteria *Methylobacterium symbioticum*, but the differences were not significant compared to the control object (Rodrigues et al. 2024). A good effect of the application of preparation with *Methylobacterium symbioticum* was obtained on maize and strawberries by Vera et al. (2024), which indicated the possibility of reducing the nitrogen dose by 50 and 25%, respectively. On average, it was shown that the yield for the two potato varieties was similar. The tuber yield obtained in the object after the application of BlueN® was higher by 6.1% compared to the control object. When using 100 kg N ha^{-1}, the tuber yield was higher by 6.5% compared to the dose of 70 kg N ha^{-1}. In a moderately dry year, the tuber yield was higher by 50.2% compared to the dry year (Table 6). The research results were consistent with the previous ones regarding the response of tuber yield to increasing levels of nitrogen fertilization (Trawczyński 2020). The possibility of partial replacement of mineral nitrogen by using various forms of biostimulating foliar fertilizers was also confirmed in relation to tuber yield (Trawczyński 2022).

Content of basic components in tubers

The factors studied affected the dry matter, starch, vitamin C and nitrate content in tubers to varying degrees. The highest dry matter content in tubers was obtained from the Tajfun variety grown on the object after the application of BlueN® at a lower nitrogen dose in a moderately dry year. In a dry year, the highest dry matter content was noted for tubers of the Hermes variety on the object with BlueN® and after the application of a dose of 70 kg N ha^{-1} (Table 4).

On average, the dry matter content of the Hermes variety tubers was 2.2% higher than that of the Tajfun variety. After applying BlueN®, the dry matter content of the tubers was 0.9% higher than that of the control object. When using a dose of 70 kg N ha^{-1}, the dry matter content of the tubers was 1.1% higher than that obtained after using the dose of 100 kg N ha^{-1}. In a similar range, the dry matter content of the tubers was higher in the dry year than in the moderately dry year (Table 5).

The effect of the experimental factors on the starch level in tubers was consistent with the dry matter content (Table 4). On average, the Hermes variety was characterized by a significantly higher starch content in tubers than the Tajfun variety. On the other hand, the remaining factors, i.e. the object and the nitrogen dose, did not significantly differentiate the starch content in tubers. Previous studies have proven a more beneficial effect of a microbiological preparation on the starch content in tubers, raising it on average by 5.9% compared to the control object (Volkogon et al. 2021). In relation to the years, it was shown that in a moderately dry year, a sig-

Table 4

The influence of the interaction of the studied factors on the content of components in tubers and the uptake of total nitrogen

Year	Variety	Without BlueN®		BlueN®		Mean
		100 kg N ha^{-1}	70 kg N ha^{-1}	100 kg N ha^{-1}	70 kg N ha^{-1}	
Dry matter (%)						
2022	Hermes	23.63 *c*	23.60 *c*	23.13 *d*	23.13 *d*	23.37 *B*
	Tajfun	22.73 *de*	23.00 *de*	23.10 *d*	23.70 *c*	23.13 *C*
2023	Hermes	24.06 *a*	23.63 *c*	23.76 *bc*	24.13 *a*	23.90 *A*
	Tajfun	22.66 *e*	22.86 *de*	22.93 *de*	24.00 *ab*	23.11 *C*
Mean		23.27 B	23.27 *B*	23.27 *B*	23.23 *B*	23.74 *A*
Starch (%)						
2022	Hermes	16.96 *a*	17.00 *a*	16.53 *ab*	16.46 *bc*	16.74 *A*
	Tajfun	15.96 *bc*	16.26 *bcd*	16.23 *cd*	16.83 *ab*	16.32 *C*
2023	Hermes	16.43 *ab*	16.56 *ab*	16.80 *ab*	16.06 *d*	16.46 *B*
	Tajfun	16.06 *bd*	16.16 *cd*	16.23 *cd*	16.13 *cd*	16.15 *D*
Mean		16.35 C	16.35 *C*	16.50 *A*	16.45 *AB*	16.37 *AB*
Vitamin C (mg kg^{-1})						
2022	Hermes	164.06 *bc*	162.36 *d*	169.06 *abc*	163.76 *cd*	164.81 *B*
	Tajfun	162.33 *d*	170.76 *ab*	165.93 *bc*	172.50 *a*	167.88 *A*
2023	Hermes	162.00 *d*	163.66 *cd*	163.00 *d*	164.00 *bc*	163.16 *B*
	Tajfun	169.33 *ab*	170.33 *ab*	156.66 e	162.33 *d*	164.66 *B*
Mean		164.43 B	164.43 *B*	166.78 *A*	163.66 *B*	165.65 *AB*
Nitrates V (mg kg^{-1})						
2022	Hermes	91.66 *ab*	71.66 *cd*	81.66 *bc*	66.00 *d*	77.75 *B*
	Tajfun	105.00 *a*	66.66 *d*	96.66 *ab*	63.33 *de*	82.91 *A*
2023	Hermes	51.00 *ef*	40.33 *fg*	30.00 *g*	39.33 *fg*	40.16 *C*
	Tajfun	52.66 *ef*	38.00 *g*	38.66 *fg*	38.00 *g*	41.83 *C*
Mean		75.08 A	75.08 *A*	54.16 *C*	61.75 *B*	51.66 *C*
Total nitrogen (g kg^{-1})						
2022	Hermes	16.5 *bc*	16.1 *c*	19.0 *a*	16.2 *c*	17.0 *A*
	Tajfun	14.4 *d*	13.9 *e*	17.0 *b*	14.5 *d*	14.9 *B*
2023	Hermes	14.3 *d*	13.1 *g*	14.6 *d*	13.5 *f*	13.9 *C*
	Tajfun	12.7 *gh*	12.3 *h*	12.8 *gh*	12.5 *h*	12.6 *D*
Mean		14.4 *B*	13.9 *D*	15.8 *A*	14.2 *C*	
Uptake of total nitrogen (kg ha^{-1})						
2022	Hermes	202.66 *cd*	188.31 *cd*	233.11*b*	196.23 *cd*	205.08 *B*
	Tajfun	208.79 *bc*	182.30 *d*	263.06 *a*	217.22 *bc*	217.84 *A*
2023	Hermes	147.71 *ef*	128.33 *fg*	153.06 *e*	141.04 *ef*	142.54 *C*
	Tajfun	97.82 *h*	83.98 *h*	106.50 *gh*	98.51 *h*	96.70 *D*
Mean		164.25 B	164.25 *B*	145.73 *C*	188.93 *A*	163.25 *B*

a, *b* (for interaction years × variety × object × dose of nitrogen); *A*, *B*, *C* (for average values); mean values indicated by the same letters are not statistically significantly different at the 0.05 level according to the Tukey's test

Table 5

The influence of the studied factors on the yield and content of components
and the uptake of total nitrogen

Feature	Variety		Object		Dose		Year	
	Hermes	Tajfun	Without BlueN®	BlueN®	100 kg N ha^{-1}	70 kg N ha^{-1}	2022	2023
Yield of tubers	47.22 *a*	47.89 *a*	46.18 *b*	48.99 *a*	49.05 *a*	46.05 *b*	57.09 *a*	38.01 *b*
Dry matter	23.63 *a*	23.12 *b*	23.27 *b*	23.48 *a*	23.25 *b*	23.50 *a*	23.25 *b*	23.50 *a*
Starch	16.60 *a*	16.23 *b*	16.42 *a*	16.41 *a*	16.40 *a*	16.43 *a*	16.53 *a*	16.30 *b*
Vitamin C	163.99 *b*	166.27 *a*	165.60 *a*	164.65 *a*	164.05 *b*	166.21 *a*	166.35 *a*	163.91 *b*
Nitrates (V)	58.95 *b*	62.37 *a*	64.62 *a*	56.70 *b*	68.41*a*	52.91 *b*	80.33 *a*	41.00 *b*
Nitrogen	15.4 *a*	13.7 *b*	14.2 *b*	15.0 *a*	15.1 *a*	14.0 *b*	15.9 *a*	13.2 *b*
N uptake	173.81 *a*	157.27 *b*	154.99 *b*	176.09 *a*	176.59 *a*	154.49 *b*	211.46 *a*	119.62 *b*

a, *b*, *c* (for average values); mean values indicated by the same letters are not statistically significantly different at the 0.05 level according to the Tukey's test

nificantly higher level of starch was obtained in tubers than in a dry year (Table 6). As a rule, dry years favor the accumulation of dry matter and starch in tubers, and the level of these components decreases with the increase in the dose of mineral nitrogen (Trawczyński 2021). Previous studies confirmed that the genetic properties of varieties significantly differentiated the dry matter and starch content in tubers and these two features were convergent (Trawczyński 2020).

This study showed a beneficial effect of BlueN® on the vitamin C content in tubers of both varieties. In a moderately dry year, after BlueN® was applied, the Hermes variety was characterized by a higher vitamin C content in tubers at a nitrogen dose of 100 kg ha^{-1}, while the Tajfun variety had a higher vitamin C content in tubers at a nitrogen dose of 70 kg ha^{-1}. In a dry year, the Tajfun variety showed a greater variation in the vitamin C content in tubers in relation to the object and nitrogen dose than the Hermes variety did (Table 4). On average, there was no significant difference in the vitamin C content in tubers between the objects, which was previously demonstrated by Volkogon et al. (2021) in favor of the microbiological preparation. Previous studies reported a beneficial effect of foliar application of nutritional and biostimulating preparations of various origins on the content of vitamin C in tubers (Trawczyński 2018). On average, tubers of the Tajfun variety contained significantly more vitamin C. A higher content of vitamin C in tubers was obtained when using a lower dose of nitrogen. In a moderately dry year, a higher content of vitamin C in tubers was noted than in a dry year (Table 5). A moderate dose of nitrogen had a beneficial effect on the level of vitamin C in tubers, similarly to years with sufficient rainfall (Trawczyński 2022).

The content of nitrates in tubers decreased with the application of

BlueN®, which confirmed the research conducted by Volkogon et al. (2021). The research by Arrobas et al. (2024) showed that the level of nitrates did not increase with the growth of lettuce after the use of a bacterial vaccine. This was a beneficial effect as nitrates are classified as antinutritional components. The Tajfun variety was characterized by a significantly higher content of nitrates in tubers than the Hermes variety, especially in a moderately dry year. The level of nitrates in tubers varied significantly in relation to the nitrogen dose, which was confirmed previously (Trawczyński 2020, 2021). The lowest level of nitrates was found in the tubers of the Hermes variety in a dry year on the object where the preparation and a nitrogen dose of 100 kg ha^{-1} were used (Table 4). On average, tubers of the Tajfun variety showed a 6% higher level of nitrates compared to the Hermes variety. On the object with BlueN®, a 14% reduction in the level of nitrates in tubers was achieved compared to the control object. When using a dose of 100 kg N ha^{-1}, the content of nitrates in tubers was recorded as 29% higher than with a dose of 70 kg N ha^{-1}. In a dry year, a lower content of nitrates was o btained in tubers (Table 5), and generally, dry years favor the accumulation of this compound in tubers (Trawczyński 2022).

Total nitrogen content and its uptake by tuber yield

Due to the possibility of nitrogen fixation from the air by the applied BlueN®, the primary goal was to determine its effect on the level of this component and its uptake by potato tubers. The effect of the BlueN® application was expressed by a significant increase in the content of total nitrogen in tubers, which depended on the variety, nitrogen dose and study years. In a moderately dry year, after the application of BlueN®, a significantly higher nitrogen content was recorded in the tubers for both varieties fertilized with a dose of 100 kg N ha^{-1} compared to the control object. In a dry year, the nitrogen content in tubers was significantly lower (Table 5). On average, a higher content of total nitrogen was shown in tubers of the Hermes variety. When using a dose of 100 kg N ha^{-1}, a significantly higher content of total nitrogen was recorded as compared to a dose of 70 kg N ha^{-1}. The use of BlueN® contributed to a significant increase in the level of total nitrogen in tubers. An increase in the nitrogen content in the grain yield of maize after the application of *Methylobacterium symbioticum*, which in the range of fertilization from 0 to 160 kg N ha^{-1} amounted to 5.2% to 18.5%. was confirmed by Rodrigues et al. (2024). Strawberry plants inoculated with *Methylobacterium symbioticum* subject to a 25% reduction in the dose of mineral nitrogen showed higher nitrogen levels in leaves than control plants under optimal nutritional conditions (Vera et al. 2024). The greatest difference in the content of total nitrogen in tubers was shown in relation to the study years (Table 5). Previous studies showed an inverse relationship, years favoring high yield accumulation were characterized by a lower content of total nitrogen in tubers (Trawczyński, Wierzbicka 2014).

The level of yield and the content of total nitrogen in tubers translated into its uptake with the yield. In a moderately dry year, the significantly highest nitrogen uptake with tuber yield was obtained for the Tajfun variety in the object where BlueN® and a dose of 100 kg N ha^{-1} were used. In turn, the significantly lowest nitrogen uptake with tuber yield was characterized by the Tajfun variety in the object without BlueN® at a dose of 70 kg N ha^{-1}. The difference in nitrogen uptake between these combinations was 44%. In a dry year, the difference between the extreme combinations was greater (Table 4). However, in the study by Rodrigues et al. (2024), no significant difference was shown in nitrogen uptake with maize yield between the object with BlueN® with *Methylobacterium symbioticum* and the control object. It was demonstrated that nitrogen uptake was more consistent with the level of tuber yield than with the content of this component in the tubers. On average, the difference in nitrogen uptake between varieties amounted to 10.5%, between objects it was 13.6%, between nitrogen doses 14.3%, and between years it was as high as 76.8% (Table 5).

The results obtained so far concerning the use of the foliar microbiological preparation BlueN®s on various species of plants are quite divergent. There is also a lack of research related to the supply of nitrogen obtained from the air using microbiological BlueN®s in relation to potato plants. This research therefore fills this gap and should be continued.

CONCLUSIONS

1. The use of BlueN® containing the bacterial strain *Methylobacterium symbioticum* had a positive effect on the increase in potato tuber yield, and suggested a possibility of reducing the dose of mineral nitrogen by 30 kg ha^{-1}.

2. In a dry year, after the application of the basic dose of mineral nitrogen supplemented with BlueN®, a significant increase in tuber yield was observed in both varieties, which was not demonstrated in the object without the preparation.

3. BlueN® contributed to a significant reduction in the content of nitrates in tubers and a significant increase in the level of total nitrogen as well as the uptake of this component with the tuber yield.

Author contributions

Conceptualization, methodology, software, formal analysis, investigation, data curation, writing – original draft, writing – review and editing, resources, visualization, supervision, project administration, funding acquisition.

Conflicts of interest

The author declares no conflicts of interest.

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