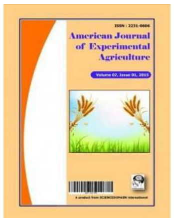

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Mineral Fertilization and Baking Value of Grain and Flour of *Triticum aestivum* ssp. *spelta* L.

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Authors' contributions

This work was carried out in collaboration between all authors. Author TK designed the study, performed field study, was involved in data collection, developed the statistical analysis and wrote the first draft of the manuscript. Authors ESF, WK, BB and BM managed the field study, guided on data collection, evaluation and interpretations. All authors designed the field study, read and approved the final manuscript.

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ABSTRACT

Aims: The aim of this study was to determine the effect of varied nitrogen fertilization and foliar application of microelements (Cu, Zn, Mn and combined application of Cu+Zn+Mn) and the effect of their interaction on the grain yield quantity and some technological parameters of grain and flour of *Triticum aestivum* ssp. *spelta* L. cv. 'Rokosz'.
Study Design: The field experiment was established with the randomized split-plot method in three replications.
Place and Duration of Study: Field study was conducted in two vegetation season (2012/2013, 2013/2014), at the Research Station in Minikowo near Bydgoszcz (53°10′2″ N, 17°44′22″ E) in Midwest Poland.
Methodology: The research factors were different levels of nitrogen fertilization (0, 20, 40, 60, 80 and 100 kg·ha^{-1}) and foliar application of microelements (Cu, Mn, Zn and combined application of Cu+Mn+Zn). The obtained grain yield from the plots was adjusted to the constant humidity of 15%.

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From each plot, representative grain samples were collected for determination of quality features i.e. falling number, protein content, wet gluten, sedimentation value, water absorption of flour and bread volume from 100 g of flour.

Results: The grain yield of spelt cv. Rokosz ranged from 4.25 to 7.51 Mg·ha^{-1}. In the season 2012/13 each increase in N by 20 kg·ha^{-1} resulted in a significant increase (from 10.7 to 29.5%) in the grain yield in relation to the control. In the second year of the study, increasing fertilization by another 20 kg N·ha^{-1} caused a significant increase in yield (from 7.8 to 10.9%) as compared with the lower fertilization treatment. All quantity parameters of spelt increased significantly (compared to control) with the increase of nitrogen fertilization level (4.3 – 28.8% in the 2012/13 season and 11.7-95.4% in 2013/14) and micronutrients foliar application (1.4 - 8.0% in 2012/13 and 2.8 – 5.9% in the 2013/14 season).

Conclusion: Each increase in the nitrogen fertilization level caused an increase in grain yield of *Triticum spelta* L. cv. 'Rokosz'. Separate and combined application of microelements resulted in a positive yield-forming effect as compared with the control. Varied fertilization with nitrogen and microelements significantly determined the values of the studied technological parameters.

Keywords: Nitrogen fertilization; micronutrients fertilization; Triticum aestivum ssp. *spelta L.; grain yield; technological parameters*.

1. INTRODUCTION

The results of research in food science, dynamically developing for years, combined with the analysis of relationships between a diet and human health, has indicated that some old plant species have been appreciated again. These plants include *Triticum aestivum* ssp*. spelta* L. Some primeval characters of its grain being rich source of valuable nutrients, are sought after by modern consumers as an attractive element of healthy diet [1-6]. In spite of lower productivity as compared with common wheat, spelt wheat is characterized not only by a higher content of nutrients, but also by lower habitat requirements and smaller outlays on the means of production, which is currently preferred in sustainable agriculture [7]. Demand for spelt wheat grain dictated by the growing market of products with desired nutritive qualities and sensory properties, forces conducting multidimensional research over factors affecting its qualitative characters and technological usefulness. The more so as the high quality of a product made from spelt wheat ensures the use of only suitable material, that is its grain, for production. The grain quality of spelt should be examined in connection with the quantity of its yield, as one of the basic characters determining the cost-effectiveness and usefulness of its cultivation. Obtaining the specific values of individual parameters is determined by the ability to select the cultivation technology suitable for the given soil and climate conditions and the level of economy, as well as the cultivar for which growing under these conditions will allow achieving the goals set by the producer. The fact that the selection of cultivars according to the further use of grain and according to the particular conditions of its cultivation plays the essential role in affecting the quantity of grain yield and its expected qualitative and technological characters, is confirmed by results of many studies [8-10]. Like the constant selection of newly introduced lines and cultivars dictated by the dynamic development of breeding work, they indicate the necessity of analysis of their response to agricultural factors, the more so because despite the widely presented problems of spelt wheat cultivation, there is no essential, explicit information concerning the response of spelt wheat cultivars currently introduced into cultivation measures, including fertilization. Determination of proper requirements concerning fertilization of cultivars of this cereal species not only will verify recommendations of breeders in relation to the levels of rates of particular nutrients, but also it may indicate their interactions. Despite low requirements of spelt in respect of nitrogen fertilization, but a rather high sensitivity to the deficit of this element, data describing the response of spelt cultivated in conditions of Poland to fertilization with this element are regarded as not sufficient. In recent years, also growing attention is focused on the favourable effect of fertilization of cereal crops with microelements, especially in the case of fertilization with nitrogen [11-14]. In the case of application of microelements in spelt wheat cultivation, there are no definite data concerning the usefulness of its application and conditions in which this measure is performed. According to Rachoń et al. [6], obtaining the high quality material is connected with the necessity of using more intensive technologies in cultivation of not only common wheat but also other wheat species regarded as the so-called extensive species, including spelt. The results obtained from the previous studies with spelt wheat in the case of its positive response to definite agricultural factors (especially fertilization) may arouse the interest of agricultural producers in growing this cereal, not only in conditions of organic farms, and constitute an alternative to growing other cereal crops. Determination of grain qualitative characters depending on agricultural factors, including varied mineral fertilization, allows broadening the state of knowledge concerning the quality and usefulness of spelt wheat grain for the purposes of food industry. The most essential parameters of baking value include undoubtedly qualitative characters characterizing the grain protein complex, i.e. protein content, wet gluten and sedimentation value. Great deal of attention is devoted to these parameters in the literature [6,15-18]. Nevertheless, the most thorough assessment of baking value is provided by the trial baking, as the direct test for usefulness of flour obtained from grain of the particular cultivar in respect of baking from it bread with expected characters, including its volume.

The aim of this study was to determine the effect of varied fertilization with nitrogen and foliar application of microelements and the influence of their interactions on the grain yield quantity and some technological parameters of grain and flour of the studied spelt wheat cultivar 'Rokosz'.

2. MATERIALS AND METHODS

The two-factorial field experiment with the *Triticum aestivum* ssp*. spelta* L. cultivar 'Rokosz' was carried out in the growing seasons 2012/13 and 2013/14 at the Agricultural Experimental Institute in Minikowo (53°10′2″ N, 17°44′22″ E, Kuyavian-Pomeranian voivodeship) owned by the University of Science and Technology in Bydgoszcz. The research factors were different levels of nitrogen fertilization and foliar application of microelements (Cu, Mn, Zn and Cu+Mn+Zn together) at the constant amount of phosphorus and potassium fertilization. The experiment was established with the randomized split-plot design in three replications. The soil where the cereal was cultivated is the typical lessive soil classified as Albic Luvisols (the very good rye complex, soil quality class III a) according to the international FAO-UNESCO classification [19]. The soil reaction was neutral and the content of available phosphorus, potassium and magnesium was very high or high. The copper content, on the other hand, was moderate and manganese and zinc appeared in amounts below the lower threshold values. The detailed physicochemical properties of the soil are given in Table 1.

Table 1. Physical and chemical soil properties

Parameter	Range	Mean
pH in KCl	6.3 – 7.0	6.7
Hydrolytic acidity mmol(+)·kg^{-1}	11.7 – 17.3	14.8
Total organic C g·kg^{-1} DM*	6.87 – 8,73	7.77
Total N g·kg^{-1} DM	0.76 – 0.83	0.81
P mg·kg^{-1} DM	68.7 – 84.1	78.6
K mg·kg^{-1} DM	174 – 216	204
Mg mg·kg^{-1} DM	52.2 – 93.7	75.7
Mn mg·kg^{-1} DM	207 – 421	377
Cu mg·kg^{-1} DM	5.56 – 7.08	6.46
Zn mg·kg^{-1} DM	6.89 – 13.64	8.59

** DM – dry matter*

The previous crop for the cultivated cereal was winter oilseed rape. All pre-sowing measures, sowing, cultivation practices during growth and harvest (stage 92-99 BBCH) were performed in accordance with agricultural requirements optimal for the studied crop. In the field where spelt wheat was grown, potassium (103 kg·ha^{-1}) and phosphorus (30 kg·ha^{-1}) were applied prior to sowing in autumn in the form of: 57% potash salt and 46% triple superphosphate, respectively. Cereals in the amount of 260 kg·ha^{-1} of grain dressed with the preparation Panoctine 350 LS (170 ml/100 kg of grain) were sown from 11th to 20th September. On research plots with an area of 20 m^2 six rates of nitrogen fertilization was applied (I factor, n=6) as well as different variants of foliar application of microelements (II factor, n=5). Nitrogen fertilization (34% ammonium nitrate) was applied at the following rates and times:

- ⇒ rates 20 kg N·ha^{-1} at the start of spring growth,
- ⇒ rates 40 kg N·ha^{-1} at the start of spring growth,
- ⇒ rates 60 kg N·ha^{-1} were divided: 40 kg at the start of spring growth and 20 kg at full shooting (stage 34-37 acc. to BBCH scale),
- ⇒ rates 80 kg N·ha^{-1} were divided: 40 kg at the start of spring growth and 40 kg at full shooting (stage 34-37 acc. to BBCH scale),

⇒ rates 100 kg N·ha^{-1} were divided: 40 kg at the start of spring growth and 40 kg at full shooting (stage 34-37 acc. to BBCH scale) and 20 kg at the beginning of earing (stage 50-51 acc. to BBCH scale).

The foliar application of microelements (Cu – 0.1 kg·ha^{-1}, Zn – 0.2 kg·ha^{-1}, Mn – 0.3 kg·ha^{-1} and Cu+Mn+Zn combined) in the form of technical salts was used at the stage of shooting (34-37 BBCH) together with foliar application of 6% water solution of urea. All measures were performed on one day after dissolving the proper amount of Cu, Mn and Zn in the water volume corresponding to 300 dm^3·ha^{-1} on one day.

The grain of spelt wheat cultivar 'Rokosz' was harvested in full grain maturity (stage 92-99 BBCH) with the plot combine harvester. Grain yield (GY) was counted over 15% water content and t·ha^{-1}. Samples were collected from each of the experimental plots to make determinations of baking indices of grain and flour of the studied cereal. After suitable preparation, in the spelt wheat ground grain the falling number value (FN) according to Hagberg was determined (PN-ISO-3093), in whole grain - the total protein content (PC) according to Kjeldahl (%N·5,7, PN-EN ISO 20483), and in spelt wheat flour: wet gluten (WG; PN-EN ISO 21415-2), the sedimentation value (SV) according to Zeleny (PN-EN ISO 5529), water absorption of flour (WA; PN-ISO 5530-1) and the volume of bread (BV) from 100 g of flour (PN-A-74108).

The results were statistically analyzed using analysis of variance, which was made with a computer program AWAR, developed in the Department of Agrometeorology and Applied Informatics, Institute of Soil Science and Plant Cultivation in Pulawy [20]. The analysis was conducted for the randomized sub-blocks design (split-plot). Elimination of non-significant differences was performed at the level p=0.05. To determine connections and relationships between the obtained values of tested features of spelt wheat, the results were subjected to analysis of simple correlations.

3. RESULTS AND DISCUSSION

3.1 Weather Conditions in the Study Region

Data concerning the course of the weather conditions were obtained from the Meteorological Station of the Agricultural Experimental Institute in Minikowo. Table 2 presents average monthly temperatures and monthly total rainfalls in the growing seasons 2012/13 and 2013/14 and for the long-term period 1949-2015.

From these data it appears that all 1st season of conducting the field experiment was characterized by slightly higher total amount of rainfall in relation to the average from the long-term period (by 6.63 mm) at the average temperature lower by 1.2℃. In contrast, in the season 2013/14 the total amount of rainfall was considerably lower than the value from the long-term period (by 99.17 mm, i.e. by 19.9%) at the same time with a higher average temperature calculated for the whole season (by 0.4℃) (Table 2). Also it should be emphasized that the average monthly temperatures from May to August 2013 and from February to July 2014 were higher in comparison with the average values from the long-term period. The relationships described above could verify the yield and quality of harvested grain of German wheat. In both growing seasons, July was characterized by the highest average monthly temperature, whereas the lowest temperature was noted in January. The highest monthly total rainfalls were observed in November 2012; in May, June and September 2013 and in May and August 2014, and the lowest amounts in April 2013 and in January and February 2014. According to Dmowski and Dzieżyc [21], March and April should be characterized by rainfalls of 42 mm, whereas in the following months there should fall 80 mm (May) and 100 mm (June) of water. From this it can be concluded that of the mentioned months, only in May 2013 and in March and April 2014 the total rainfall exceeded the recommended amount.

3.2 Grain Yield

From the subject literature, it appears that the data concerning spelt wheat yielding are not explicit. According to Pospišil et al. [8], spelt wheat give yields at a similar level to common wheat. In the investigations done by Lacko-Bartošová et al. [22] in western Slovakia, yields of spelt grain ranged, in dependence on the cultivar, from 5.38 to 6.76 Mg·ha^{-1}. According to Lacko-Bartošova and Otepka [23] the yield of spelt wheat cultivars ranged from 77.2 to 92.2% of common wheat yield. Rachoń et al. [7] observed the grain yield of spelt wheat at the level 7.77 t·ha^{-1} and it was lower than those of common wheat and durum wheat by 18.7 and 17.0 %, respectively. Lower yielding of

Table 2. Weather conditions during the vegetation seasons (2012/13 and 2013/14) and 1949-2015

Month	Average temperature (ºC)			Rainfall (mm)		
	Vegetation season		1949-2015	Vegetation season		1949-2015
	2012/2013	2013/2014		2012/2013	2013/2014	
September	13.5	11.9	13.4	29.60	55.80	42.73
October	7.7	9.7	8.1	32,50	21,80	34.15
November	5.0	4.7	3.4	59,90	29,10	35.86
December	-1.8	2.3	-0.2	25,70	25,80	36.04
January	-2.8	-2.9	-2.0	52,10	18,00	30.20
February	-0,2	2,5	-1.3	47,20	21,20	23.55
March	-2,7	6,0	2.1	39,10	46,60	27.89
April	7,0	10,2	7.5	13,20	42,20	29.22
May	14,4	13,3	12.7	97,40	54,80	47.90
June	16,9	16,2	16.2	59,00	29,00	54.84
July	18,2	21,6	17.9	48,20	49,60	78.25
August	18,1	17,4	17.4	31,00	61,40	58.01
Mean/total	6,8	8,4	8.0	505,30	399,50	498.67

spelt in comparison with common wheat is connected with the significantly lower thousand kernel weight, grain weight per ear and grain bulk density. In the author's present study the average grain yield of the spelt cv. Rokosz in the growing seasons 2012/13 and 2013/14 was at the level 6.81 and 5.38 $t \cdot ha^{-1}$, respectively (Table 3). In the second year of the study it was lower by 21% than in 2012/2013, mainly due to the rainfall deficit in June and July (Table 2). The obtained relationships confirm the effect of the weather conditions during the growing period on cereal yield reported by other authors [24,25]. Rainfall deficits during earing, flowering and grain formation may have a negative impact on yield-forming effect and yield quality of cereal grain [26]. In both years of the study the grain yield quantity was significantly determined by the applied varied soil nitrogen fertilization (it is also confirmed by highly statistically significant values of simple correlation coefficients; Table 4), as well as by the variants of foliar application of microelements. In the first season of the conducted experiment, each increase in the nitrogen fertilization level (by 20 $kg \cdot ha^{-1}$) resulted in a statistically proved increase in grain yield in relation to the treatment without fertilization. Whereas in the second year, increasing fertilization by another 20 kg $N \cdot ha^{-1}$ resulted in a significant increase in grain yield in comparison with the lower fertilization treatment. In the experiment carried out by Bepirszcz and Budzyński [27] application of 30 kg $N \cdot ha^{-1}$ allowed obtaining the grain yield of spelt at the level 5.2 $t \cdot ha^{-1}$, increasing the fertilization rate of this component up to 102 $kg \cdot ha^{-1}$, caused an increase in yield up to about 6.0 $t \cdot ha^{-1}$. This, like in the case of the results of the author's study from 2013, indicates a high yield-forming potential of spelt and limited usefulness of applying high rates of nitrogen.

Application of mineral fertilizers with micronutrients results in a higher yield and content of mineral components in grain [28-30]. Foliar application of microelements (Cu, Mn, Zn and combined application of Cu+Mn+Zn) resulted in an increase in yield in relation to the control treatment, and the level of statistical significance for the study from 2013 was obtained only after the use of Zn, whereas for the study from 2014 after the use of Mn only and Zn only (Table 3). In the study by Wojtkowiak and Stępień [30], where Cu, Mn and Zn were applied in spelt wheat cultivation, the highest grain yields of this cereal were found after the application of copper (5.98 $Mg \cdot ha^{-1}$). And the lowest as a result of spraying with Zn (5.63 $Mg \cdot ha^{-1}$).

3.3 Technological Parameters

Falling number (FN) indicates to only storage usefulness, but first of all, technological usefulness of grain for flour production and its further use in the bread industry [31]. In the present experiment, irrespective of the studied factors, average values of this qualitative character of spelt stayed at the level 410 s (2013) and 260 s (2014) (Table 5). High values of FN, similar to the first year of the present study, were found in the studies by other authors [7,32,33]. Although the high FN value of spelt, showing a low activity of alfa-amylase, does not disqualify the grain in question as a material in bread industry, it indicates the need for making mixtures of flours obtained from it with flour from common wheat [34]. Thanks to that the obtained bread will be characterized by a better taste and smell and a higher nutritional value. Apart from that, the fact that baking from spelt flour alone, in spite of exceptional healthful properties, will not fulfil demands of the average consumer due to its worse fermentation properties, argues for the use of mixtures. The average FN values of spelt wheat cultivated in the growing season 2013/14 obtained in the present experiment were similar to the values presented by other authors [9,11,35,36], but slightly lower than those found by Capouchová [37] and Marconi et al. [1].

In the first year of conducting the experiment, the falling number value of the spelt wheat cultivar Rokosz was significantly affected by nitrogen fertilization, microelement application and interaction of those factors, whereas in the second year of the study, only fertilization with nitrogen (Table 5). In the season 2012/13 the use of 60, 80 and 100 kg N·ha^{1} caused obtaining significantly higher values of the index in question as compared with the control (391 s), respectively by: 5.1, 11.0 and 12.3%. Of the microelements, the highest, statistically proved effect on the falling number value was found as a result of the application of Mn and combined application of Cu+Mn+Zn, Its highest value, in turn, as a result of interaction of the research factors was obtained after the application of 100 kg N·ha^{-1} and Cu. In the second year of the study, the application of 60 kg N·ha^{1} and each increase in this element by 20 kg N·ha^{1} resulted

Table 3. Grain yield [Mg·ha^{-1}] of *Triticum aestivum* ssp. *spelta* L. cv. 'Rokosz' after the application of fertilizers

	Fertilization level [kg·ha^{-1}]					
Nitrogen	**Microelements**					
	0	**Cu (0.1)**	**Mn (0.3)**	**Zn (0.2)**	**Cu+Mn+Zn**	**mean***
2012/2013						
0	5.07	5.41	5.96	6.31	6.26	5.80^{d}
20	6.42	6.26	6.33	6.75	6.36	6.42^{c}
40	6.80	6.61	6.63	7.32	6.78	6.82^{bc}
60	7.08	7.11	6.91	7.36	7.13	7.12^{ab}
80	7.15	7.24	7.01	7.44	7.22	7.21^{ab}
100	7.34	7.90	7.24	7.61	7.44	7.51^{a}
mean**	6.64^{c}	6.75^{bc}	6.68^{bc}	7.13^{a}	6.87^{abc}	6.81
2013/2014						
0	3.81	4.17	4.35	4.47	4.43	4.25^{f}
20	4.24	4.62	4.60	4.74	4.68	4.58^{e}
40	5.07	5.00	5.02	5.21	5.05	5.07^{d}
60	5.41	5.71	5.44	5.77	5.58	5.58^{c}
80	6.04	6.16	6.35	6.33	6.07	6.19^{b}
100	6.71	6.56	6.81	6.61	6.47	6.63^{a}
mean**	5.21^{b}	5.37^{ab}	5.43^{a}	5.52^{a}	5.38^{ab}	5.38

** means marked with different letters in columns differ significantly at α = 0.05*
*** means marked with different letters in lines differ significantly at α = 0.05*

Table 4. Values of significant correlation coefficients between the features of wheat

Parameter[#]	**N**	**GY**	**FN**	**PC**	**WG**	**SV**	**WA**	**BV**
	2012/2013				**2013/2014**			
N	-	0.98***	0.94***	0.93***	0.98***	0.97***	0.96***	0.93***
GY	0.87***	-	0.93***	0.92***	0.98***	0.97***	0.94***	0.93***
FN	0.78***	0.67***	-	0.79***	0.96***	0.97***	0.89***	0.89***
PC	0.91***	0.78***	0.84***	-	0.88***	0.87***	0.92***	0.93***
WG	0.88***	0.76***	0.87***	0.98***	-	0.99***	0.95***	0.91***
SV	0.91***	0.80***	0.86***	0.97***	0.97***	-	0.93***	0.92***
WA	0.91***	0.98***	0.87***	0.97***	0.98***	0.97***	-	0,.90***
BV	ns	0.42**	ns	0.35*	ns	0.35*	ns	-

[#] N – N fertilization, GY – grain yield, FN – falling number, PC – protein content, WG – wet gluten, SV – sedimentation value, WA – water absorption of flour, BV – bread volume
, ** and *, Significant at P ≤0.05; 0.02 and 0.01 probability level, respectively, ns: Non significant*

Table 5. The values of technological parameters of *Triticum aestivum* ssp. *spelta* L. cv. 'Rokosz' after the application of fertilizers

Fertilization	Parameter					
	Falling number	Protein content	Wet gluten	Sedimentation value	Water absorption of flour	Bread volume
	s	g·kg^{-1}	%	cm^3	%	cm^3
Nitrogen			**vegetation season 2012/13**			
0	391^{c}	127^{c}	32.4^{c}	36.8^{e}	57.2^{c}	419^{b}
20	387^{cd}	129^{c}	32.5^{c}	37.8^{de}	57.5^{c}	423^{ab}
40	396^{bc}	131^{c}	32.6^{c}	38.3^{d}	57.9^{c}	428^{ab}
60	411^{b}	139^{b}	35.1^{b}	42.0^{c}	59.9^{b}	418^{b}
80	434^{a}	145^{ab}	36.5^{ab}	45.2^{b}	61.0^{ab}	428^{ab}
100	439^{a}	151^{a}	37.4^{a}	47.4^{a}	61.6^{a}	437^{a}
Microelements	*	*	-	*	-	-
0	402^{b}	133^{b}	33.5^{b}	38.9^{c}	58.4^{b}	420
Cu	412^{ab}	137^{a}	34.8^{a}	41.4^{ab}	59.3^{a}	429
Mn	416^{a}	139^{a}	34.9^{a}	42.4^{a}	59.7^{a}	415
Zn	402^{b}	137^{a}	34.3^{ab}	41.2^{b}	59.2^{ab}	431
Cu+Mn+Zn	416^{a}	139^{a}	34.4^{a}	42.0^{a}	59.2^{ab}	433
Mean	410	137	34.4	41.2	59.2	425
Nitrogen			**vegetation season 2013/14**			
0	195^{d}	107^{f}	21.2^{f}	25.3^{f}	53.6^{f}	392^{f}
20	204^{d}	115^{e}	22.0^{e}	27.4^{e}	54.0^{e}	424^{e}
40	210^{d}	123^{d}	24.0^{d}	29.0^{d}	56.6^{d}	437^{d}
60	270^{c}	125^{c}	26.3^{c}	31.7^{c}	57.6^{c}	449^{c}
80	299^{b}	127^{b}	28.6^{b}	36.1^{b}	58.5^{b}	460^{b}
100	381^{a}	130^{a}	31.4^{a}	40.0^{a}	59.9^{a}	485^{a}
Microelements	-	-	*	-	-	*
0	258	118^{b}	25.0^{c}	30.5^{c}	56.3^{b}	426^{c}
Cu	255	121^{a}	25.4^{bc}	31.4^{b}	56.8^{ab}	443^{b}
Mn	261	122^{a}	25.6^{b}	31.7^{b}	57.0^{a}	440^{b}
Zn	260	121^{a}	26.2^{a}	32.5^{a}	56.7^{ab}	445^{b}
Cu+Mn+Zn	266	122^{a}	25.7^{ab}	31.9^{b}	56.7^{ab}	451^{a}
Mean	260	121	25.6	31.6	56.7	441

a, b, c, d, e, f - values followed by the same letter in each column in each fertilization, are not significantly different at the 0.05 level according to the Tukey's test

***** *significant interaction: nitrogen fertilization x micronutrients fertilization*

in obtaining significantly higher values of the falling number as compared with lower fertilization treatments (Table 5). The significant effect of nitrogen fertilization on the falling number value indicated in the present study has not been confirmed by the literature data [12].

The most important indices of baking value include undoubtedly quality factors characterizing the grain protein complex, i.e. protein content (PC), wet gluten (WG) and sedimentation value (SV). In the present study, average values of those characters, irrespective of the studied factors, stayed, respectively, at the level: 137 g·kg^{-1}, 34.4% and 41.2 cm^3 (2012/2013) as well as 121g·kg^{-1}, 25.6% and 31.6 cm^3 (2013/2014) (Table 5). Much higher contents of total protein in spelt wheat grain, as compared with the present study, were found by Biel et al. [5] and Rachoń et al. [6], whereas lower ones by Szumiło et al. [33] and Mikos i Podolska [9]. Similar or higher results concerning wet gluten, in comparison with those obtained in 2013, were found in studies by other authors [4,6,8,32,35]. Sedimentation index values obtained in 2013 confirmed the results of the study by Marconi [1], and those obtained in 2014, the study by Krawczyk et al. [38]. The literature data emphasize large fluctuations in protein content, wet gluten and sedimentation value, depending on the grown lines and cultivars [9,35,38] or the determining effect of the year of cultivation [32]. In the present experiment, the total protein content, wet gluten and the sedimentation index were significantly determined by varied rates of nitrogen, which is also confirmed by calculated significant values of simple correlation coefficients (Table 4), and variants of application of microelements. Moreover, the protein content and sedimentation value in 2013 and wet gluten in 2014 was determined by interaction of the studied factors (Table 5). In the first year of the study, the use of nitrogen rates at the level 60 kg·ha^{1} caused a significant increase in protein content and wet gluten, as compared with the control and treatments N_{20} and N_{40}. In the case of the sedimentation index, the rate 40 kg N·ha^{1} turned out to be significant in comparison with the control. Increasing rates by 20 kg N·ha^{1} (N_{60}, N_{80}, N_{100}) above this rate (N_{40}) caused a significant increase in the sedimentation index by another 9.7; 7.6 and 4.9%. In the season 2013/2014, on average each increase in nitrogen fertilization level caused a significant increase in values of all the indices in question characterizing the protein complex (PC, WG, SV) of the spelt wheat cultivar Rokosz (Table 5). Biel et al. [5] observed an increase in total protein content in grain of spelt wheat cultivars as affected by an increase in nitrogen rates from 133 to 179 g·kg^{-1} d.m. In the study by Rachoń et al. [6], intensification of cultivation technology, involving, among other things, increasing nitrogen fertilization level from 70 to 100 kg·ha^{-1}, resulted in an increase in protein content from 171 to 189 g·kg^{-1} and wet gluten from 37.2 to 42.5%. According to Rachoń et al. [39], the higher nitrogen fertilisation rate (140 kg ha^{-1} N compared to 70 kg ha^{-1} N) resulted in increased protein (by 1.6 percentage points). In order to obtain the most favourable cultivation technology of spelt wheat grown as the material for consumer purposes, it is necessary to determine its response expressed, among others, by values of PC, WG and SV, not only to the amount of nitrogen fertilization rates, but only of applied microelements (Table 5). In both years of the study, irrespective of nitrogen fertilization, the use of all the variants of microelement application caused a significant increase in total protein content and sedimentation index values in comparison with the treatment without fertilization, and in the case of wet gluten, only with the exception of the application of zinc in 2013 and copper in 2014. Protein contents as compared with the control, in the case of the foliar application of Mn only or the combined application of Cu, Mn and Zn, were higher by 4.5% (2012/2013) and 3.4% (2013/2014), respectively, and after the application of Cu or Zn only, by 3% (2012/2013) and 2.5% (2013/2014), respectively (Table 5). On the treatments fertilized with a particular microelement (Cu, Mn, Zn) and combined microelements (Cu+Mn+Zn), a similar content of total protein was observed in both years and of wet gluten in the growing season 2012/2013. In the second year of conducting the experiment, the most favourable wet gluten (WG) was obtained after the application of zinc, which caused a significant increase in the value of this character not only in comparison to the treatment without fertilization, but also to those fertilized with copper and manganese. In the case of sedimentation value (SV), the highest value confirmed with the level of statistical significance, in the growing season 2013/2014 was found as a result of the use of zinc, and in the growing season 2012/2013, of the use of manganese, whereas it was significantly higher, apart from the control treatment, only in comparison with SV obtained from the treatment fertilized with zinc. The studies by other authors [12,30] inform about the significant effect of microelements on the values of baking parameters of cereal grain characterizing the protein complex (PC, WG, SV). Similarly to studies of other authors [6,12,15], a significant positive correlation has been noted between total protein content in the grain and other technological parameters.

The water absorbability (WA) of flour obtained from milling of grain of the studied Grain wheat cultivar Rokosz, irrespectively of the experimental factors, amounted to 59.2% (2013) and 56.7% (2014) (Table 5). The results of the present study from the growing season 2012/2013 are similar to the values of this parameter obtained by other authors [35,36], whereas from the growing season 2013/2014, to those obtained by Ralcewicz et al. [15] and by Krawczyk et al. [38]. In the conducted experiment the value of the character in question was significantly determined by varied nitrogen rates and variants of microelement application. Irrespective of the application of microelements, the use of increased rates of nitrogen (similarly to studies of Ralcewicz et al. [15]), in the whole range, caused an increase in flour water absorbability. The application of nitrogen fertilization, with the rate of 60 kg·ha^{-1} in the first year of the study and 40 kg N·ha^{-1} in the second year, caused on average a significant increase in the water absorbability of spelt flour as compared with the treatments fertilized with lower rates and without fertilization (Table 5). As far as WA is concerned, the most favourable variants of fertilization with microelements, irrespective of nitrogen fertilization, was fertilization only with copper (2013) or only with manganese (2013 and 2014), whereas the level of statistical significance was obtained only in comparison with the treatments without fertilization (Table 5).

The average bread volume (BV) produced from 100 g of flour obtained from milling of the spelt wheat cultivar Rokosz amounted to 426 cm^3 and 441 cm^3 (Table 5). Considerably lower volumes of spelt wheat bread were obtained in other studies [34]. Majewska et al. [40], depending on the studied cultivar, observed considerably lower or similar values (from 323 cm^3 to 426 cm^3). In the study carried out by Szumiło et al. [33] in turn, the average bread volume from spelt flour stayed at the level 390 cm^3. Similarly to studies of Ralcewicz et al. [15], in our experiment increase in nitrogen doses applied to the soil has resulted an increase bread volume (Table 4). Both in the first and second years of the study, the most favourable BV was obtained as a result of the application of 100 kg $N \cdot ha^{-1}$, whereas in the growing season 2012/2013 it was significantly higher only in comparison with the bread volume value obtained after the application of 60 kg $N \cdot ha^{-1}$ and from the treatment without fertilization. In this situation it should be stated that the justified nitrogen rate for the bread volume is a rate of 20 $kg \cdot ha^{-1}$. In 2014 each increase in the nitrogen fertilization level caused an increase in the volume of bread obtained from 100 g of spelt flour of cv. Rokosz (Table 4). Application of 60 kg $N \cdot ha^{-1}$ resulted in a significant increase in BV and in comparison with the lower research treatment, this value was higher by: 2,7% (N_{40}), 5.9% (N_{20}) and 14.5% (N_{0}). Increasing nitrogen fertilization by another 20 $kg \cdot ha^{-1}$, i.e. to 80 kg $N \cdot ha^{-1}$, resulted in further increase in bread volume, significant in comparison with treatments N_{40}, N_{20} and N_0, but not proved statistically in relations to the treatment N_{60}. The application of 100 kg $N \cdot ha^{-1}$ in turn resulted in obtaining a significantly higher BV in relation to all the lower research treatments, namely higher from 5.4 to 23.7%. Relationship between the volume of bread obtained from flour of various cereals and the nitrogen fertilization level is confirmed by studies by many authors [12,15]. The results obtained and calculated based on the presented experiment indicate that in the growing season 2013/2014, both the application of Cu, Mn, Zn, Cu+Mn+Zn and the interaction of soil nitrogen fertilization and foliar application of microelements, significantly positively determined the value of bread volume (Table 4). The highest bread volume from 100 g of German wheat flour, irrespective of nitrogen fertilization, was found after the combined application of Cu+Mn+Zn and it was significantly higher than the values obtained from the other research treatments within the range from 1.4 to 5.9%. The bread volume values obtained from the treatments where particular, single microelements were applied were characterized by significantly higher values only in comparison with the treatment without the application of microelements.

4. CONCLUSION

Each increase in the nitrogen fertilization level, within the whole range of the rates applied, caused on average an increase in the grain yield of spelt wheat cultivar Rokosz and it was significant in the growing season 2012/2013 in comparison with the control treatment, whereas in the growing season 2013/2014 in comparison with the lower research treatment.

The foliar application of microelements (Cu, Mn, Zn and combined Cu+Mn+Zn) caused an increase in yielding as compared with the control treatment, whereas the level of statistical significance in the growing season 2012/2013 was obtained only as a result of application of Zn, whereas in the growing season 2013/2014, after the application of Mn and Zn.

The applied varied nitrogen fertilization significantly determined the values of studied qualitative and technological indexes, and only in the growing season 2013/2014 each increase in the level of this element caused on average significant increase in total protein content, wet gluten and sedimentation value.

Irrespective of nitrogen fertilization, the use of individual and combined microelements caused an increase in values of the studied technological characters as compared with the treatment without fertilization.

Cultivation of new lines and cultivars of speltt obtained as a result of dynamically progressing breeding work, allows better use of the supplied nitrogen and justifies the application of microelements in order to obtain a high yield with grain quality parameters corresponding to high quality of material.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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