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Research Article

Mineral Composition and Baking Value of the Winter Wheat Grain under Varied Environmental and Agronomic Conditions

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The mineral composition of cereal crops, the technological value of grain and flour, as well as bread quality are affected by the genotype, environment, and agronomic management practices. The aim of the research has been to investigate the effect of the environment and agronomic factors on the mineral composition and baking value of winter wheat grain. Opal cultivar grain of the genetically determined prime-quality wheat was obtained in a two-year field experiment (varied soil and weather). The agronomic management practices included tillage (conventional moldboard-plow, reduced ploughless, and strip-till) and nitrogen fertilisation rate (100 kg·N·ha^{-1}, 200 kg·N·ha^{-1}). In the grain samples, the content of macronutrients was assayed: P, K, Mg, Ca, and Na, total protein, and wet gluten as well as sedimentation value. The colour and the water absorption of flour and its content of protein and ash were determined. Laboratory baking was performed. It was found that the content of protein and gluten in grain, sedimentation value, bread volume, and weight changed depending on the environmental conditions and research years. Tillage and nitrogen rate, despite an effect on the properties of grain and flour, did not differentiate, however, the bread quality. The environmental conditions and agronomic management practices did not have a significant effect on the content of mineral nutrients in grain, except for calcium. The biofortification with mineral nutrients in prime-quality winter wheat cultivar grain by selecting the environmental and agronomic conditions seems more difficult than increasing the content of organic compounds and enhancement of flour and bread parameters.

1. Introduction

The cereal grain is the core of human nutrition. The increase in the human population, changes in diet, a versatile use of grain in food, and biofuels industry creates the need for increasing its production [1–3]. The grain of wheat, the most important crop, next to rice, corn, and soybean [4], is allocated for human consumption and for animal feed. After processing, it is used for flour, groats, cereals, pastas, and bread or added to other food and feed products [5–8]. It essentially affects the health of people and livestock [9]. Wheat cultivation, the largest area of arable crops in the world, also shapes the environment, soil, water, and air quality [10]. The aim of contemporary plant breeding and agronomic practices is thus not only increasing the grain production but also enhancing its quality, including an increase in the content of organic compounds and mineral nutrients. Grain biofortification allows the application of the latest methods of genetic engineering and technology advances in agricultural production [11]. Irrespective of the wheat grain use, it must be of a very good quality which depends on the physical and chemical properties [12, 13], as well as biochemical and functional traits [14]. The grain quality depends on the content of organic compounds (protein and its fractions, carbohydrates, and fat), mineral nutrients (phosphorus, calcium, potassium, magnesium, and microelements), vitamins, antioxidants, and antinutritional compounds [15, 16]. The content and the properties of starch are very important, including the basic components of amylose and amylopectin. They determine the technological and nutrition quality of grains [17]. A special biological and performance function is played by protein, especially the gluten fraction. Gliadin and glutenin ensure dough elasticity and extensibility [18]. Gluten determines softness, elasticity, and cohesion of bread both fresh and after storage [19]. The baking value of grain and flour describes many traits, most importantly those which characterize its enzymatic complex (falling number) and protein complex (the content of total protein and wet gluten and sedimentation value). A comprehensive evaluation, however, is only provided by a baking test, including the bread volume evaluation [20, 21].

The content of macronutrients and micronutrients as well as other grain quality traits are genetically determined. The effect is so strong that wheat cultivars, depending on the grain quality, are divided into a few classes. In Poland and in many other countries, those are, for example, elite wheat, prime-quality wheat, bread wheat, and forage wheat [22, 23]. Next to the effect of the genotype, the grain quality traits also depend on the environmental conditions and agronomic management practices [24, 25]. A sunny weather and a low amount of precipitation after the postanthesis stage increases the content of protein and gluten and the sedimentation value. Nitrogen fertilisation makes a similar effect [26, 27]. Wheat grain biofortification can be increased by other elements of agronomic practices. To get to know the effect of tillage and seeding, many field experiments were performed [28–30]. An even greater effect on wheat grain properties can be found for fertilisation with macronutrients and micronutrients [31, 32]. However, the research results are not unambiguous. In many cases, especially when the variation in the agronomic factors is low, it does not affect the grain quality or significant interactions cultivar × environment, cultivar × agronomic practices occur [33, 34].

The confirmation of the research hypothesis (H_1) on the effect of the factors on the grain composition points to its possible biofortification by selecting the conditions of cereal cultivations. However, then the grain produced in different environmental and agronomic conditions has a different value, which makes it difficult to receive large batches of homogenous material. Rejecting hypothesis H_1 and accepting zero hypothesis (H_0) point to a lack of a significant effect of the environment and agronomic management practices on the grain quality. It is possible when the effect of the genotype on the grain composition is very strong and the variation in its production conditions is relatively low. One can then produce large batches of homogenous quality grain; however, a possibility of its biofortification is limited.

The aim of the present research has been to evaluate the effect of the environment and agronomic management practices on the composition and baking value of the grain of wheat with a good technological quality genetically determined.

2. Materials and Methods

2.1. Field Experiment. To verify the hypotheses, a field experiment was performed in two seasons of winter wheat cultivation: 2013/2014 and 2014/2015. Under varied soil conditions and varied weather patterns, there was investigated the effect of three tillage methods (conventional moldboard-plow, reduced ploughless, and strip-till) and two nitrogen fertilisation rates (100 kg·N·ha^{-1} and 200 kg·N·ha^{-1}) on the content of macronutrients and the traits of the baking value of winter wheat grain. The experiment was made in a split-plot design, in four replications. The research involved the use of winter wheat, Opal cultivar, with a very good genetically determined technological quality of grain for bread baking, the prime-quality wheat. A variation in environmental conditions throughout the research period is presented in Table 1. In both years during harvest, the average grain sample was taken from each experiment treatment for laboratory evaluation.

2.2. Grain and Flour Analysis. For the representative grain samples, the following macronutrients were assayed:

(i) The content of potassium, calcium, and sodium (flame photometry method with Flapho4, after an earlier plant material mineralization in H_2SO_4),

(ii) The content of magnesium (with the atomic absorption spectrometry, using Varian AA240FS, after an earlier plant material mineralization in H_2SO_4),

(iii) The content of phosphorus with the colorimetric method with flow analyzer San++ by Skalar.

The grain and flour colour was assayed with colorimeter CR-410 (Konica Minolta). Total protein content, wet gluten, sedimentation value, water absorption of flour, protein content of flour, and ash content there were determined using the InfratecTM 1241 Grain Analyzer (FOSS Analytical AB, Sweden). It is a near-infrared transmission (NIT) instrument which is capable of simultaneous and accurate determination of several constituents in whole grain samples. The essence of the measurement is the radiation absorption in the near-infrared range by the main grain components.

2.3. Bread Evaluation. The value of the direct baking index, which is bread volume, was obtained after performing the single-phase baking process. Dough was prepared from 400 g of flour, 6 g of table salt, 12 g of baker's yeast, and an adequate amount of water, which depended on the water absorption of a given flour sample. The ingredients were mixed in a lab mixer for 10–15 minutes. The dough was placed into the fermentation chamber (30°C) for 30 minutes. After that time, the dough was manually mixed and again placed in the fermentation chamber for 30 minutes. It was formed and two 300-gram water-moistened dough portions

Table 1: Environmental conditions at the experimental site.

Soil property	2013/2014	2014/2015
Sand fraction (%)	42.7	39.5
Silt fraction (%)	52.6	54.0
Clay fraction (%)	4.7	6.5
pH_{KCl}	5.9	6.2
Organic carbon ($g{\cdot}C{\cdot}kg^{-1}$ soil)	11.2	11.6
Total nitrogen ($g{\cdot}N{\cdot}kg^{-1}$ soil)	0.9	1.5
Available phosphorus by Egner–Riehm ($mg{\cdot}P{\cdot}kg^{-1}$ soil)	113.4	98.7
Available potassium by Egner–Riehm ($mg{\cdot}K{\cdot}kg^{-1}$ soil)	186.9	205.3
Available magnesium by Schachtschabel ($mg{\cdot}Mg{\cdot}kg^{-1}$ soil)	58.0	64.2
Meteorological conditions	2013/2014	2014/2015
Sum of precipitation in the winter wheat growing season (mm)	369.2	296.8
Sum of precipitation at postanthesis stage of winter wheat (mm)	90.9	97.8
Mean air temperature in the winter wheat-growing season (°C)	8.1	8.3
Mean air temperature at postanthesis stage of winter wheat (°C)	18.5	16.9

were put into lab casts for bread baking and again exposed to fermentation for about 30 minutes. Then, the loaves were moistened with water and put into the oven (230°C) for 30–35 minutes. The bread weight was determined twice, immediately after it was taken out from the oven and 24 hours after receiving the bread. The baked bread volume was measured with the volumeter.

With the bread results, the loaf volume from 100 g of flour (X) was calculated.

$$X = \frac{a \times b}{c}, \qquad (1)$$

where a is the loaf volume (cm^3), b is the weight of the dough received from 100 g of flour (g), and c is the weight of the dough formed for baking (g).

Baking loss (Y) and total baking loss (YT) were also determined.

$$Y = \frac{(a-b)100}{a}, \qquad (2)$$

$$\mathrm{YT} = \frac{(a-c)100}{a}, \qquad (3)$$

where a is the weight of the dough formed for baking (g), b is the weight of bread once it is taken out from the oven (g), and c is the weight of bread 24 after baking (g).

2.4. Statistical Analysis of the Results. The results were statistically analyzed using the Statistica 12.5 package. The multiple analysis of variance was applied. There was determined the significance of the effect of respective experimental treatments and their interaction on 22 traits of grain, flour, and bread. The treatments were as follows: research year, tillage, nitrogen rate, and interactions: tillage × nitrogen rate, research year × tillage, research year × nitrogen rate, and research year × tillage × nitrogen rate. Of the 88 interactions, 4 were significant, for example, a varied effect of nitrogen fertilisation in research years on the content of protein and gluten in grain. With that in mind, the tables present only the effect of the main treatments on the grain-quality traits pointing to significant interactions in the discussion of the results. The significance of the differences between the means of the treatment levels was estimated with post hoc Tukey test at $P = 0.05$.

3. Results and Discussion

The research point to a poor effect of the environment (varied soil and weather over study years) and agronomic management practices (tillage and fertilisation) on the content of mineral nutrients in winter wheat grain (Table 2). The content of all the macronutrients in grain in both years was similar. Only conventional tillage and strip-till as well as a higher nitrogen rate ($200\,kg{\cdot}N{\cdot}ha^{-1}$) increased the content of calcium in grain, as compared with a reduced tillage and a low nitrogen rate ($100\,kg{\cdot}N{\cdot}ha^{-1}$). In the 2014/2015 season, the differences were significant; in the first research year, tendencies were recorded. Wheat grain after strip-till and conventional tillage contained 16.7–22.2% more calcium than that after reduced tillage. An increase in the content of calcium in grain due to a higher nitrogen rate accounted for 27.8%. However, the tillage did not differentiate the content of phosphorus, potassium, magnesium, and sodium in grain. Neither did the study by Stanisławska-Glubiak and Korzeniowska [35] confirm the effect of a strongly reduced tillage—zero tillage on the content of mineral nutrients in cereal grain, including winter wheat.

Lee et al. [36] show that the content of calcium in cereal grain varies a lot. The coefficient of variation in the content of calcium in wheat grain from five countries with various climate, soil, and agronomic conditions was almost 5-fold higher than that of phosphorus. The effect of environmental and agronomic conditions on the concentration of mineral nutrients in grain depends on the genotype. Hussain et al. [37] found that the location of the wheat plantation affected the mineral composition of grain in primitive varieties more than in contemporary cultivars. The content of mineral nutrients and other wheat grain quality traits is strongly affected by weather, especially precipitation and temperature after anthesis [38, 39]. According to Zhao et al. [40], the water conditions in soil in that period have a significant effect on the content of phosphorus, potassium, calcium, and magnesium as well as organic compounds: protein, fats, and starch. A lack of significant variation in the mineral composition of winter wheat grain in years in the present research could have been due to a low variation in the environmental conditions, soil, and the weather pattern. The difference in the amount of precipitation over the grain-filling stage was only 7 mm, while the difference in the mean air temperature was higher. In 2014, it was 1.6°C higher than that in 2015, which was favourable for the accumulation of protein in grain.

The content of total protein in grain and in flour, wet gluten in grain, and the sedimentation value for wheat grown in the 2013/2014 season were higher than that in

Table 2: Mineral composition of grain depending on the research year, tillage, and nitrogen fertilisation (experimental treatments).

Treatment	Mineral nutrients ($g \cdot kg^{-1}$ d. m.)				
	P	K	Mg	Ca	Na
2013/2014	3.06[a]	6.65[a]	1.01[a]	0.21[a]	0.14[a]
2014/2015	3.15[a]	6.51[a]	1.01[a]	0.20[a]	0.14[a]
Conventional	3.08[a]	6.65[a]	1.05[a]	0.22[a]	0.14[a]
Reduced	3.09[a]	6.58[a]	0.99[a]	0.18[b]	0.14[a]
Strip-till	3.14[a]	6.51[a]	0.99[a]	0.21[a]	0.14[a]
100 $kg \cdot N \cdot ha^{-1}$	3.04[a]	6.74[a]	1.01[a]	0.18[b]	0.14[a]
200 $kg \cdot N \cdot ha^{-1}$	3.17[a]	6.42[a]	1.01[a]	0.23[a]	0.14[a]

[a,b]Results that differ statistically in columns.

Table 3: Quality of grain and wheat flour depending on the research year, tillage, and nitrogen fertilisation (experimental treatments).

Treatment	Quality parameter					
	Protein content in grain ($g \cdot kg^{-1}$ d. m.)	Content of wet gluten (%)	Sedimentation value (cm^3)	Water absorption of flour (%)	Protein content in flour ($g \cdot kg^{-1}$ d. m.)	Ash content in flour (%)
2013/2014	125.6[a]	30.8[a]	39.7[a]	62.2[a]	120.6[a]	0.73[a]
2014/2015	123.0[b]	30.3[b]	38.5[b]	61.9[a]	116.1[b]	0.72[a]
Conventional	122.7[b]	30.5[a]	39.8[a]	61.9[a]	118.3[a]	0.72[a]
Reduced	122.7[b]	30.2[a]	38.4[a]	61.8[a]	117.2[a]	0.74[a]
Strip-till	126.1[a]	30.5[a]	39.0[a]	62.3[a]	119.6[a]	0.73[a]
100 $kg \cdot N \cdot ha^{-1}$	114.4[b]	27.6[b]	31.9[b]	61.3[b]	111.3[b]	0.73[a]
200 $kg \cdot N \cdot ha^{-1}$	133.3[a]	33.5[a]	46.3[a]	62.7[a]	125.4[a]	0.73[a]

2014/2015 (Table 3). A favourable effect of a high, although not excessively high, temperature after anthesis and fertilisation, especially with nitrogen, on the accumulation of protein in grain has been confirmed in many earlier reports [41, 42]. In the present research, all the grain and flour quality traits related to the content of nitrogen and protein showed a higher value when accompanied by a higher nitrogen fertilisation. Grain, following the application of 200 $kg \cdot N \cdot ha^{-1}$, contained significantly more protein and gluten, and it showed a higher sedimentation value; flour demonstrated higher water absorption, and it contained more protein, as compared with the grain of wheat fertilised with 100 $kg \cdot N \cdot ha^{-1}$. A favourable effect of the higher nitrogen rate on the content of protein and gluten in grain and the sedimentation index was greater in the first year than in the second research year. Higher protein content in grain was found also when growing wheat following the strip-till technology than after a conventional tillage or a reduced ploughless tillage. A favourable effect of strip-till on the protein content in grain can be due to the nature of this tillage method and sowing. With that technology, the first rate of fertilisers is applied only into rows, localised fertilisation, and not into the entire space of the soil under tillage. Localised fertilisation results in a greater concentration of nutrients in the neighbourhood of plants and their better nutrition [43]. A variable environment and the agronomic treatments did not have a significant effect on the ash content in flour, although Alijošius et al. [44] point to a high variation in that trait. The authors cited, however, investigated the grain of six wheat cultivars, and not one cultivar, which can point to a high genetic variation and not environment-agronomic variation of that trait.

The research evaluated the effect of the environment and agronomic management practices on the parameters of the colour of grain and flour (Table 4). Value L^*, determining the colour lightness, was 47.9–48.5 and 88.2–88.5, respectively, and it did not depend on the research year, tillage, and nitrogen fertilisation. Parameter a^*, defining the variation in the grain colour from green to purple, was significantly higher in the 2014/2015 season and due to a lower nitrogen rate. The nitrogen rate at the amount of 100 $N \cdot ha^{-1}$ as compared with the rate of 200 $N \cdot ha^{-1}$ also increased the value of colour parameter b^*, whereas tillage did not have a significant effect on any grain and flour colour parameter.

The enzymatic and protein complex of grain as well as the water absorption of flour affect the baking parameters, for example, bread volume and weight. Laboratory baking allows a comprehensive evaluation of grain and flour as it facilitates an immediate observation of dough and then bread [45, 46]. The volume of the bread baked from flour received after milling of grain of the winter wheat cultivar studied ranged from 411 to 449 cm^3. The results show a greater effect of the environment on the volume and weight of bread right after baking than agronomic management practices (Table 5). There was no confirmed direct effect of nitrogen fertilisation on bread volume, whereas such effect was reported by other authors [47]. One can assume, however, that a significantly greater bread volume and weight from grain were received in the 2014/2015 season, and a clear tendency towards a greater bread volume from grain after strip-till resulted from nitrogen management in soil. In the second research year, soil contained slightly more total nitrogen, and the precipitation during the wheat

Table 4: Colour of grain and wheat flour received in varied environmental and agronomic conditions (experimental treatments).

Treatment	Colour					
	Grain			Flour		
	L*	a*	b*	L*	a*	b*
2013/2014	48.2[a]	10.9[b]	13.8[a]	88.2[a]	4.56[a]	9.11[a]
2014/2015	48.3[a]	11.2[a]	13.9[a]	88.4[a]	4.50[a]	9.19[a]
Conventional	48.4[a]	11.0[a]	13.8[a]	88.5[a]	4.57[a]	9.29[a]
Reduced	48.3[a]	11.0[a]	13.8[a]	88.3[a]	4.53[a]	9.10[a]
Strip-till	47.9[a]	11.2[a]	13.9[a]	88.2[a]	4.49[a]	9.06[a]
100 kg·N·ha^{-1}	48.5[a]	11.2[a]	14.2[a]	88.2[a]	4.53[a]	9.21[a]
200 kg·N·ha^{-1}	47.9[a]	10.9[b]	13.5[b]	88.4[a]	4.53[a]	9.09[a]

L*, a*, and b* are parameters of grain and flour colour.

Table 5: Properties of bread depending on the environmental and agronomic conditions of grain production—experimental treatments.

Treatment	Bread volume (cm^3)	Bread weight (g)		Loss (%)	
		After baking	After 24 h	Baking loss	Total baking loss
2013/2014	415[b]	286.0[b]	274.8[a]	4.67[a]	8.40[a]
2014/2015	441[a]	290.3[a]	279.1[a]	3.23[a]	6.98[a]
Conventional	423[a]	288.1[a]	277.3[a]	3.98[a]	7.56[a]
Reduced	411[a]	289.0[a]	277.7[a]	3.65[a]	7.45[a]
Strip-till	449[a]	287.3[a]	275.8[a]	4.22[a]	8.07[a]
100 kg·N·ha^{-1}	428[a]	286.6[a]	275.3[a]	4.48[a]	8.22[a]
200 kg·N·ha^{-1}	428[a]	289.7[a]	278.5[a]	3.42[a]	7.16[a]

vegetation period was lower, which limits its leaching [48]. Strip-till technology, on the contrary, results in the application of fertilisers immediately under plants. Those conditions could have resulted in a greater availability of nitrogen and its uptake by plants.

Baking loss and the total baking loss did not depend on the environmental conditions in the research years, tillage and nitrogen fertilisation. It shows a similar dough quality and its changes during baking [49]. Baking loss is thus a loss of weight during baking due to a loss of water and volatile substances, such as CO_2, alcohol, and volatile acids.

4. Conclusions

Strongly genetically determined traits of the baking value of winter wheat grain were significantly modified due to environmental conditions. Even inconsiderable differences in the soil properties and weather pattern in years affected the content of protein and gluten in grain as well as the baking quality parameters of flour and bread. Thus, the location and the region of the wheat plantation can affect the quality of grain, as well as flour and bread received from it. However, the agronomic management practices, including tillage and nitrogen fertilisation, despite an effect on the properties of grain and flour, related to the protein complex, did not differentiate the bread quality. The grain of the prime-quality winter wheat cultivar did not change in terms of the basic mineral nutrients, including phosphorus, potassium, magnesium, and sodium both due to environmental and agronomic conditions. The calcium content in grain was the only one which depended on tillage and nitrogen fertilisation. The biofortification of prime-quality winter wheat cultivar grain with macronutrients by selecting the plantation location and agronomic management practices seems more difficult than an increase in the content of organic compounds, mostly total protein and wet gluten, as well as an enhancement of flour and bread parameters.

Data Availability

No data were used to support this study.

Conflicts of Interest

The authors have declared no conflicts of interest.

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