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THE EFFECT OF TILLAGE SYSTEM AND NITROGEN FERTILIZATION ON NUTRITIONAL VALUE OF WINTER SPELT WHEAT CULTIVARS

WPŁYW SYSTEMU UPRAWY I NAWOŻENIA AZOTEM NA SKŁAD CHEMICZNY ODMIAN ORKISZU OZIMEGO

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Streszczenie. Doświadczenie polowe zostało wykonane w Rolniczej Stacji Doświadczalnej Zachodniopomorskiego Uniwersytetu Technologicznego w Szczecinie w Lipniku koło Stargardu Szczecińskiego w latach 2009−2011. Czynnikami badawczymi w doświadczeniu były: systemy uprawy (uproszczony i orkowy), wybrane odmiany i rody orkiszu pszennego (‘Frankenkorn’, ‘Oberkulmer Rotkorn’, ‘STH 8’, ‘STH 11’, ‘STH 12’) oraz poziomy nawożenia azotem (kontrola – zero, 50, 100, 150 kg azotu · ha^{-1}). Materiał badawczy stanowiły próby ziarna, uzyskane jako średnie dla kombinacji doświadczalnych. W próbkach ziarna oznaczono podstawowy skład chemiczny oraz frakcje włókna. Wyniki przedstawionych badań wykazały, iż istnieją możliwości kształtowania zawartości składników odżywczych decydujących o wykorzystaniu ziarna orkiszu w przemyśle spożywczym poprzez czynniki agrotechniczne. Wyższe dawki azotu istotnie zwiększyły zawartości białka ogółem (154 g · kg^{-1}). Odmiany i rody miały istotny wpływ na zawartość białka ogółem (154 g · kg^{-1}), tłuszczu (19.3 g · kg^{-1}) i popiołu surowego (20.8 g · kg^{-1}) oraz frakcji włókna pokarmowego neutralnodetergentowego (114 g · kg^{-1}) i kwaśnodetergentowego (33.3 g · kg^{-1}).

Key words: conventional tillage, reduced tillage, *Triticum spelta* L., nitrogen fertilization, nutrients.
Słowa kluczowe: uprawa tradycyjna, uprawa uproszczona, *Triticum spelta* L., nawożenie azotowe, składniki odżywcze.

INTRODUCTION

Interest in the ancient, hexaploid spelt (*Triticum spelta* L.) has returned in connection with the development of alternative agriculture and desire to preserve biodiversity. In addition, the increase in acreage of spelt has resulted from the overproduction of general cereals, introduction of environmentally friendly cultivation technologies, and growing consumers' interest in new products. Spelt has long been grown in Germany, Austria, Switzerland,

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Belgium, Italy, Czech Republic, Slovakia, Slovenia, as well as in Canada, USA, and Australia. Its grain contains large amounts of essential nutrients such as protein, fiber, unsaturated fatty acids, carbohydrates, vitamins, and micronutrients, which favorably distinguishes it from other cereals (Majewska et al. 2007; Yang et al. 2011; Zhen et al. 2015).

The quality of wheat grain is the result of genetic characteristics, soil and climate conditions, as well as applied cultivation technology. Among cultivation treatments, the largest role is attributed to nitrogen fertilization, because this factor has a significant impact on the quantity and quality of protein in grains. High doses nitrogen in the case of certain wheat cultivars have a positive influence on the qualitative features (Nowak et al. 2004). Achremowicz et al. (1995) reported that nitrogen applied at later development stages of wheat enhances the gliadin content in protein, thus some traits of gluten get worsened. In opinion of Budzyński et al. (2004), the grain quality also depends on the tillage system and combination of that feature with nitrogen rate. Tillage is of a great importance in ensuring the proper conditions during the sowing as well as plant growth and development. This is achieved by optimizing the physical, chemical and biological soil properties. Traditional system of cultivation based on the plow and other mechanical procedures, that is commonly used in our country, destroys natural structure of the soil, causing its over-drying and accelerating the mineralization of organic matter (Dzienia et al. 2006; Morris et al. 2010). Therefore, there is a growing interest in different solutions limiting the mechanical interference in the soil. A simplified tillage (plowless), in which the incorporation of plant remains into the surface layer, while remaining part of them on the soil surface, becomes the most popular (Małecka et al. 2012). Introducing some simplifications to the tillage brings a number of advantages such as: prevention of soil erosion, intensification of biological life in the soil, increase of organic matter content and soil moisture, reduction of fuel consumption, reduction of exhausted gases and carbon dioxide emissions as well as air pollution. Simplified tillage can also modify the concentration of nutrients in wheat grain, improving plumpness and uniformity of grains as well as protein and wet gluten contents (Małecka and Blecharczyk 2004). The surface tillage (simplified) and direct sowing increases the agricultural and physiological efficiency and the use of mineral fertilizers by spring barley (Małecka and Blecharczyk 2005).

Available literature contains little research findings upon the consequences of a long-term impact of simplified tillage systems on the quality of crops. Therefore, the aim of this study was to analyze the influence of genetic factors, nitrogen fertilization, and tillage system on the chemical composition of spelt grains.

MATERIAL AND METHODS

Conditions of the experiment conducting

The field experiment was carried out at the Agricultural Experimental Station of the West Pomeranian University of Technology in Szczecin, in Lipnik near Stargard Szczeciński in 2009−2011. The experimental factors consisted of: tillage systems (simplified and plow), selected cultivars and strains of spelt (‘Frankenkorn’, ‘Oberkulmer Rotkorn’, ‘STH 8’, ‘STH 11’, ‘STH 12’), and nitrogen fertilization levels (control – 0, 50, 100, 150 kg N · 1 ha^{-1}). The material for the experience purchased in Germany (‘Frankenkorn’, ‘Oberkulmer Rotkorn’) and in the company PLANT BREEDING Strzelce l.l.c. group IHAR (‘STH 8’, ‘STH 11’, ‘STH 12’).

The research station is located in the Goleniów-Pyrzyce climate area covering the Szczecin Lowland and areas located to the west of the Oder river. The terrain is located at a height of 20 to 60 m a.s.l. and is mainly lowland in nature. The region is under the influences of transitional climate characterized by warm and no-precipitation spring, as well as long and moist autumn, and droughts often occurring in summer. Rainfall sum fluctuates in the range of 500 mm and the average temperatures oscillate at the level of 8°C. The length of the growing season ranges from 205 to 225 days and begins on the first decade of April.

Soil, the experiment were performed on, belongs to the light ones of good rye complex and bonitation class IV b (arable soil of average quality – better, according bonitation soil class). It is brown rusty soil with granulometric composition of light loamy sand with weak-silty sand underneath and with light loam in some places. The humus layer has thickness about 20–25 cm and humus content about 1.6 – 1.7%. Soil acidity in 1 M KCl is pH 6.30. Content of available minerals in the soil oscillates around medium levels (P – 58 mg · kg^{-1}, K – 100 mg · kg^{-1}).

Oat was the forecrop for spelt in all study years. After the forecrop harvest, following cultivation treatments were applied: phosphorus fertilization at the dose of 100 kg · ha^{-1} in form of single superphosphate, potassium at the dose of 150 kg · ha^{-1} in form of potassium salt 60%, magnesium at the dose of 25 kg · ha^{-1}, and calcium at the dose of 124 kg · ha^{-1} as Kizerite (all doses of fertilizer are in the oxide form); post-harvest tillage was made using skimming set directly after the harvest. Prior to sowing, depending on the tillage system, pre-sow plowing using Campbell roller for plowing system and disc harrow with string roller for simplified system, was applied. The sowing was performed in 24–25 September using the sowing machine equipped in Øyorda system. Nitrogen fertilization at the first dose of 50 kg · ha^{-1} was applied at the vegetation beginning (17–19 March), while the second dose (50 +50 kg · ha^{-1}) was used during the shooting stage (21–24 April) and the third nitrogen dose (50 + 50 + kg · ha^{-1}) during heading (17–21 May) in a form of ammonium nitrate 34%. Depending on conditions in a given year and special needs, fungicidal and insecticidal protection was used, as well. The harvest was carried out using the plot combine-harvester (Wintersteiger).

Methodology of chemical analysis

Chemical analyses were carried out on grain ground in a 1095 (Foss Tecator) laboratory grinder. Basic chemical composition was determined using standard methods according to AOAC (2012). In order to determine the dry matter, the samples were dried in an oven at 105°C until a constant mass was obtained. Fat as ether extract was determined using diethyl ether according to the Soxhlet method and crude ash was determined by burning in a muffle furnace at 580°C for 8 h. Crude protein (N × 6.25) was determined according to the Kjeldahl method using a Büchi Scrubber B414 mineralisation kit and a Büchi 324 (Switzerland) distillation kit. Crude fibre (CF) was assessed according to the Hennenberg-Stohmann gravimetric method. The content of total carbohydrates was calculated according to the equation: total carbohydrates = 100 – (percentage content of protein in dry mass + fat content + crude fibre content + ash content).

The detergent fibre fractions: neutral detergent fibre (NDF), acid detergent fibre (ADF), acid detergent lignin (ADL) were determined according to the method by Van Soest et al. (1991) using an 220 Fiber Analizer (Ankom Technology Co., Fairport, NY). The NDF fraction was determined with sodium lauryl sulphate (SLS), the ADF fraction with cetyl-trimethyl-ammonium bromide (CTAB), the ADL fraction with breakdown of the obtained ADF in 72% sulphuric acid. Hemicellulose content was calculated as a difference between NDF and ADF and cellulose – as a difference between ADF and ADL.

Statistical analysis

Achieved results were subject to the triple-factor analysis of variance in a randomized block design, where the replicates consisted of results of the subsequent years of tests. The confidence semi-intervals were calculated using Tukey's test at the significance level of $p < 0.05$.

RESULTS AND DISCUSSION

Reaction of studied spelt cultivars to the tillage system and nitrogen fertilization was similar in different years of the experiment. Thus, the results were interpreted as an average of the three harvest years.

Chemical composition of the analyzed samples showed a variation depending on factors studied (Tables 1–4).

No effect of tillage system and nitrogen fertilization on dry matter, fat, crude fiber, crude ash, total carbohydrates, acidic-detergent fiber fraction, acidic-detergent lignin, hemicellulose, and cellulose contents, was recorded. The quality parameters of spelt grain were not significantly modified by the tillage system. Assessing the nutritional value and feed usefulness of cereal grains, much attention is paid to the amount of total protein. Grain protein has a significant influence on processing quality, such as dough rheological properties, baking quality, and attributes of a final product. Present study revealed nearly 8% of total protein more in the grain grown under plowless system as compared to the plowing tillage (Table 1). Mc Conkey et al. (2002) argue that grain from the plowless systems has a higher concentration of total protein. Protein levels were significantly differentiated by tested cultivar of spelt (Table 2) as well as it was subject to changes under the influence of applied nitrogen fertilization (Table 1). Higher doses of nitrogen fertilization increase the productive heading and reduce dying of side shoots, and thus increase the number of ears. The dose of nitrogen favorably affects the structure and fertility of a spike (Podolska 2008). The results indicate that increasing levels of nitrogen fertilization contribute to the increase in the protein content of grain. Increase of nitrogen rate to 150 kg · ha^{-1} had significant impact on increased protein content by 26%. A positive association of nitrogen fertilization with protein concentration in grain was confirmed by literature data. Wróbel and Szempliński (1999) reported that the increase in nitrogen dose from 0 up to 160 kg · ha^{-1} caused increase in protein content by 3.3%. In general, nitrogen fertilization makes protein levels in spelt grain higher; there are only discrepancies related to this growth range and modifying influence of environmental factors.

Table 1. Influence of farming systems and nitrogen fertilization on the basic chemical composition [g · kg^{-1}] of spelt wheat grain. Mean for 2009–2011
Tabela 1. Wpływ systemu uprawy i nawożenia azotem na podstawowy skład chemiczny [g · kg^{-1}] ziarna pszenicy orkiszowej. Średnie z lat 2009–2011

Item Cechy	Farming system System uprawy (FS)		Nitrogen fertilization Nawożenie azotem (N)				$LSD_{0.05}$ $NIR_{0,05}$	
	simplified uproszczony	plow płużny	0	50	100	150	FS	N
Dry weight Sucha masa	897.0	897.0	898.0	897.0	896.0	897.0	n.s.	n.s.
Crude protein Białko ogółem (N × 6.25)	140.0	133.0	122.0	127.0	144.0	154.0	n.s.	6.9
Crude fat Tłuszcz surowy	17.6	17.9	18.1	17.8	17.6	17.6	n.s.	n.s.
Crude fibre Włókno surowe	15.6	15.8	17.6	16.2	14.8	14.3	n.s.	n.s.
Crude ash Popiół surowy	19.1	17.2	17.9	17.2	20.2	17.3	n.s.	n.s.
Total carbohydrates Węglowodany ogółem	705.0	712.0	722.0	720.0	700.0	694.0	n.s.	n.s.

n.s. – not significant – nieistotne.

Table 2. Influence of cultivar and strain on the basic chemical composition [g · kg^{-1}] of spelt wheat grain. Mean for 2009–2011
Tabela 2. Wpływ odmiany i rodu na podstawowy skład chemiczny [g · kg^{-1}] ziarna pszenicy orkiszowej. Średnie z lat 2009–2011

Item Cecha	Cultivar – Odmiana		Strain – Ród			Mean Średnia	$LSD_{0.05}$ $NIR_{0,05}$
	‘Frankernkorn’	‘Oberkulmer Rotkorn’	‘STH 12’	‘STH 11’	‘STH 8’		
Dry weight Sucha masa	897.0	898.0	897.0	897.0	896.0	897.0	n.s.
Crude protein Białko ogółem (N × 6.25)	154.0	139.0	125.0	133.0	133.0	137.0	6.20
Crude fat Tłuszcz surowy	18.2	19.3	17.8	16.6	16.9	17.8	1.66
Crude fibre Włókno surowe	15.1	16,3	16.3	15.4	15.6	15.7	n.s.
Crude ash Popiół surowy	18.4	18.6	16.2	20.8	16.6	18.1	1.14
Total carbohydrates Węglowodany ogółem	692.0	704.0	722.0	710.0	714.0	709.0	n.s.

n.s. – not significant – nieistotne.

Cultivars tested in the experiment showed significant differentiation of protein content in grain. The lowest concentration of this component was recorded in strain ‘STH 12’, while considerably more in ‘Frankernkorn’ cultivar (154 g · kg^{-1}), which was confirmed by results obtained by Munoz-Ins et al. (2016). Experiments carried out by Sulewska et al. (2005) indicated that protein content in grain of tested spelt genotypes ranged from 133 g · kg^{-1} to 196 g · kg^{-1}. For instance, average protein content in grain one of the oldest bread cereal, i.e. common wheat (*Triticum aestivum* L.), was determined by Bian et al. (2015) for mean value of 126 g · kg^{-1}, total protein. Clamot (1984) during study upon 164 spelt forms, found great diversity of protein content in grain resulting from the genotype and localization, hence cultivation treatments and environmental factors. The level of global protein yield in wheat has remained relatively stable, despite an increase in productivity of this crop (Zlatska 2005).

Crude fiber is not a homogeneous component of plants; it is not hydrolyzed by sulfuric acid and sodium hydroxide, is made of cellulose and hemicelluloses, and is inlaid with lignin. A cultivar had no significant impact on the content of this component in tested spelt grain. It has been found an average of 15.7 g crude fiber per 1 kg of grain (Table 2). The increased nitrogen fertilization affected the unchanged level of crude fiber content, while neutral-detergent fraction (NDF) decreased (Table 3). Presented study revealed that the increase in nitrogen rate up to 100 kg · ha^{-1} exerted remarkable impact on this fraction content decrease by almost 10%. Podolska (2008) reported that both nitrogen fertilization dose, application manner, and form of applied fertilizer, had the influence on tested qualitative parameters.

Table 3. Influence of farming systems and nitrogen fertilization on the fibre fractions [g · kg^{-1}] of spelt wheat grain. Mean for 2009–2011
Tabela 3. Wpływ systemu uprawy i nawożenia azotem na frakcje włókna [g · kg^{-1}] ziarna pszenicy orkiszowej. Średnia z lat 2009–2011

Item Cecha	Farming system System uprawy (FS)		Nitrogen fertilization Nawożenie azotem (N)				$LSD_{0.05}$ $NIR_{0,05}$	
	simplified uproszczony	plow płużny	0	50	100	150	FS	N
NDF	114.0	109.0	118.0	113.0	107.0	107.0	n.s.	4.1
ADF	31.8	32.1	31.1	33.8	32.6	30.4	n.s.	n.s.
ADL	8.4	8.9	8.8	9.3	8.3	8.2	n.s.	n.s.
HCEL	82.2	76.9	86.9	79.8	74.6	76.8	n.s.	n.s.
CEL	23.4	23.3	22.3	24.5	24.3	22.3	n.s	n.s.

n.s. – not significant – nieistotne, NDF – neutral detergent fibre – włókno neutralnodetergentowe, ADF – acid detergent fibre – włókno kwaśnodetergentowe, ADL – acid detergent lignin – lignina, HCEL – hemicellulose – hemiceluloza, CEL – cellulose – celuloza.

The fat content, to a much greater extent than proteins, carbohydrates, and fiber, determines the total energy contained in grain. The cultivar and strain factor had significant effect on the lipid content in spelt grain (Table 2). Remarkably the highest level of fat was found in grain of 'Oberkulmer Rotkorn' cultivar (19.3 g · kg^{-1}), while the lowest in grain of 'STH 11' strain (by 14%). Marconi et al. (1999) found in five spelt cultivars grown in European countries, up to 44 g · kg^{-1} of fat, on average.

Grain ashability is an important indicator of the grain suitability for milling. The highest content of mineral compounds determined as an ash was found in grain of 'STH 11' strain (2.1%), followed by Swiss 'Oberkulmer Rotkorn' and German cultivar 'Frankenkorn'. Studies performed by Cacak-Pietrzak et al. (2013) revealed 19 g · kg^{-1}. of ash in spelt grain, which was higher than in the common wheat grain. This can be explained by the smaller dimensions of grains and associated higher proportion of seed coat, while lower of endosperm in kernel.

Like in other cereals, the basic part of the dry weight of spelt grain consists of the total carbohydrates. In the group of carbohydrate components dominates grain starch. In addition to starch, dextrins and soluble sugars are present in smaller quantities. Concentration of total carbohydrates did not show significant changes under the influence of tillage system, nitrogen fertilization, nor varietal factor. The average content of total carbohydrates was 709 g · kg^{-1} of spelt grain (Table 2).

The functional nature of the food is associated, among others, with the presence of contained fiber, which are carbohydrates non-digestible in the small intestine and being a substrate for bacterial microflora in the large intestine (Dhingra et al. 2011; Fuller et al. 2016). It has been shown that due to its characteristics, dietary fiber is important in the prevention and treatment of diabetes, obesity, atherosclerosis, heart diseases, and colon and colorectal cancer (Ferguson 2005; Mann and Cummings 2009). The interaction of dietary fiber with a human body is related not only to the amount of fiber in a diet, but also its fractional composition, which can vary depending on the plant species, degree of maturity, anatomical portion of the raw material, and technological process applied (Mc Dougall et al. 1996). Tillage system had no effect on the fiber fraction content (Table 3). Nitrogen fertilization significantly influenced only on the level of NDF fractions containing cellulose, hemicellulose and lignin. Along with the increase of nitrogen fertilization, content of the fiber decreased. A similar dependence was reported by Biel et al. (2011) for oat grain, in which increased nitrogen fertilization had a significant impact on lowering the NDF fraction (by 6 g · kg^{-1}). Cultivar and strain factor had a significant effect on NDF and ADF fiber fractions (Table 4).

Table 4. Influence of cultivar and strain on the fibre fractions [g · kg^{-1}] of spelt wheat grain. Mean for 2009–2011
Tabela 4. Wpływ odmiany i rodu na frakcje włókna [g · kg^{-1}] ziarna pszenicy orkiszowej. Średnia z lat 2009–2011

Item Cecha	Cultivar – Odmiana		Strain – Ród			Mean Średnia	$LSD_{0.05}$ $NIR_{0,05}$
	'Frankernkorn'	'Oberkulmer Rotkorn'	'STH 12'	'STH 11'	'STH 8'		
NDF	108.0	110.0	114.0	112.0	113.0	111.0	5.4
ADF	30.6	33.3	31.2	31.7	33.1	32.0	2.48
ADL	8.4	9.0	8.4	8.7	8.7	8.7	n.s.
HCEL	77.2	76.8	82.7	80.7	80.3	79.5	n.s.
CEL	22.2	24.2	22.9	23.0	24.4	23.3	n.s.

n.s. – not significant – nieistotne, NDF – neutral detergent fibre – włókno neutralnodetergentowe, ADF – acid detergent fibre – włókno kwaśnodetergentowe, ADL – acid detergent lignin – lignina, HCEL – hemicellulose – hemiceluloza, CEL – cellulose – celuloza.

The largest quantities of neutral-detergent fiber were found in strain 'STH 12', and the smallest in 'Frankenkorn' cultivar. On average, 111 g · kg^{-1} NDF fiber was determined in tested spelt cultivars. Fayt et al. (2008) reported almost three times higher content of this fiber fraction in spelt grain. Level of acidic-detergent fraction (ADF), containing cellulose and lignin, varied in tested samples (Table 4). Significantly less ADF fraction was found in 'Frankenkorn' cultivar. The level of other fiber fractions did not differentiate in terms of genetic factor. Lignin is deposited in cell walls at the end of cellular growth after complete development of multi-sugar skeleton of walls. The average content of lignin was 0.87%, confirming the results obtained by Escarnot et al. (2010). Hemicelluloses (HCEL) are an important component of dietary fiber having, besides pectins, strong heavy-metal-absorbing properties, thus improving nutritional value of a diet. Tested spelt grain contained 8%

hemicellulose, on average. High concentration of hemicellulose is very favorable phenomenon, because it plays positive physiological role associated with these constituents ability to swelling and water absorption in human's digestive tract (Nawirska 2005). In practice, cellulose fibers are not digested in the gut, instead it largely supports the intestine peristalsis (Kahlon et al. 2007). Tested spelt grain was characterized by cellulose content about 23.3 g · kg^{-1}.

CONCLUSIONS

1. Tillage system had no significant effect on the studied characteristics of spelt grain.
2. Increasing doses of nitrogen affected the significant increase of total protein.
3. Cultivar and strain factor influenced on the content of total protein, crude fat and crude ash as well as neutral-detergent and acidic-detergent dietary fiber fractions.
4. Significantly largest amounts of the total protein were found in 'Frankenkorn' cultivar, while the smallest in 'STH 12' strain as compared to the other cultivars.

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Abstract. The field experiment was carried out at the Agricultural Experimental Station of the West Pomeranian University of Technology in Szczecin, in Lipnik near Stargard Szczeciński in 2009−2011. The experimental factors consisted of: tillage systems (simplified and plow), selected cultivars and strains of spelt (‘Frankenkorn’, ‘Oberkulmer Rotkorn’, ‘STH 8’, ‘STH 11’, ‘STH 12’), and nitrogen fertilization levels (control – 0, 50, 100, 150 kg N · ha^{-1}). Material for the study included samples of grain obtained as an average for the experimental combinations. In samples of grain were determined the basic chemical composition and fiber fractions. The research indicates that there are opportunities to shape the size of nutrient levels, which determines the use of spelt grain in the food industry by agronomic factors. Higher nitrogen fertilization significantly increased content of total protein (154 g · kg^{-1}). Cultivar and strain factor had significant effect on the content of total protein (154 g · kg^{-1}), crude fat (19.3 g · kg^{-1}) and crude ash (20.8 g · kg^{-1}) as well as neutral-detergent (114 g · kg^{-1}) and acidic-detergent dietary (33.3 g · kg^{-1}) fiber fractions.