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Improvement of the spring wheat nutritional value by sowing variety mixtures

Poprawa wartości pokarmowej ziarna pszenicy jarej poprzez siewy mieszanin odmianowych

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The aim of the study was to determine the content of nutrients and bioactive substances in two- and three-variety mixtures of spring wheat in comparison to varieties growing in pure stand and to demonstrate whether this method of grain production allows, in addition to better yielding, improvement of its nutritional value. The material for analysis consisted of 14 varieties and 60 varietal mixtures, including 10 two-component mixtures harvested in the years 2014, 2016 and 2018. The content of protein, lipids, minerals and starch, constituting nutrients and dietary fibre, including its basic components and phenolic compounds, was determined as bioactive substances of cereal grains. The results showed that the improvement of the end-use value of spring wheat is possible by cultivating varietal mixtures. The genetic factor had a significant impact on the content of nutrients and the complex of dietary fibre in the variety mixture of spring wheat. Identification of suitable varieties for mixed sowing is necessary to improve the nutritional value of spring wheat.

Keywords: nutrients, bioactive components, two-component mixtures, three-component mixtures, mixture components

Praca miała na celu określenie zawartości substancji odżywczych i bioaktywnych w ziarnie mieszanin odmianowych, dwu i trójskładnikowych, pszenicy jarej w porównaniu do ziarna odmian wchodzących w skład tych mieszanin z siewu czystego oraz wykazanie czy ten sposób produkcji ziarna umożliwia, oprócz lepszego plonowania, także poprawę jego wartości pokarmowej. Materiał badawczy stanowiło ziarno 14 odmian oraz 60 mieszanek, w tym 10 dwuskładnikowych, z lat zbioru 2014, 2016 i 2018. Oznaczono zawartość białka, lipidów, składników mineralnych i skrobi, składających się na substancje odżywcze, a także błonnika pokarmowego, jego podstawowych składników oraz związków fenolowych, włączając alkilorezorcynole jako substancje bioaktywne w ziarnie zbóż. Wyniki badań wykazały, że poprawa wartości użytkowej ziarna jest możliwa poprzez uprawę mieszanek odmianowych pszenicy jarej. Czynnik genetyczny miał istotny wpływ na zawartość substancji odżywczych oraz kompleksu błonnika pokarmowego w ziarnie mieszanin odmianowych pszenicy jarej. Identyfikacja odpowiednich odmian do siewów mieszanych jest niezbędna do poprawy wartości użytkowej ziarna pszenicy jarej.

Słowa kluczowe: składniki odżywcze, składniki bioaktywne, mieszaniny dwuskładnikowe, mieszaniny trójskładnikowe, komponenty mieszanin

Introduction

Variety mixtures of the same cereal species enjoy great interest in Poland and other countries of the European Union due to their suitability for integrated agricultural production to obtain crops of the highest nutritional value and safety for human health. A variety mixture is defined as a mixture of at least two varieties intended for sowing, allowing cereal producers to maximize the individual positive traits of each variety and to mask the less favourable traits (Dai et al., 2012). In the case of spring cereals, the most popular are mixtures of wheat and barley varieties. Growing variety mixtures increases biodiversity and thus ensures better use of environmental resources, while reducing the occurrence of diseases and pests (Gacek et al., 1996; Finckh et al., 2000; Leszczyńska, 2010; Vera et al., 2013). When efforts are focused on achieving these goals, the selection of varieties is very important, and it cannot be done at random (Cheema et al., 1988; Nadiak, Tratwal, 2012). The positive effect of mixed sowing can only be achieved if there is a positive interaction between the varieties included in the mixture (Kiær et al., 2009), and the habitat conditions where they are grown (Leszczyńska, 2010). When the selection of mixture components is correct,

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biotic and abiotic stresses are better buffered during the whole growing season, yielding is more stable, and the obtained grain yields are of better quality and usually higher compared to the yields of mixture components grown in monoculture (Finckh et al., 2000; Kiær et al., 2009). The main criteria for selecting varieties for mixtures are differences in resistance to the most important diseases, as well as similar plant height and similar maturation period (Gacek et al., 1996; Nadziak, Tratwal, 2012). The research carried out so far has revealed lower severity of diseases (up to 60-80%) in more genetically diverse mixtures compared to fields where mixture components were grown in monocultures (Gacek et al., 1996). The compensation was lower with regard to yielding and ranged from 1% to 15%, depending on the mixture of varieties used and environmental conditions (Gacek et al., 1996; Finckh et al., 2000; Kiær et al., 2009).

Poland has a long tradition of large-scale cultivation of cereal mixtures. This is one of the features for which Polish agriculture stands out in the European Union. Currently, cereal mixtures are third or fourth most important in the structure of cereal crops, ahead of such basic crops as barley and oats, and equal to rye. According to Statistics Poland (2019), in 2019 the harvest area of cereal mixtures was 930,000 ha. Most popular are interspecific mixtures of spring cereals, barley, wheat and oats grown for feed purposes. This trend is changing in favour of variety mixtures, because of the negative effect of oats on the nutritional value of the mixture. Wheat variety mixtures are gaining interest as a grain for bread making (Żmijewski, 2004; Lee et al., 2006; Jost et al., 2015). In Switzerland, more than 10% of bread wheat crops are variety mixtures (Jost et al., 2015).

The aim of the study was to determine the content of nutrients and bioactive substances in two- and three-component variety mixtures of spring wheat in comparison to varieties grown in a pure stand, and to demonstrate whether this positive effect can be attributed to certain mixture components. This study was part of a research task carried out under the Multiannual Programme IHAR-NRI, concerning the selection of cereal varieties and legume varieties for mixed sowing in different agroclimatic conditions in Poland.

Material and Methods

All grains originated from field experiments established in the COBORU experimental network in 2014, 2016 and 2018, at three Experimental Stations for Variety Assessment: Przecław, Słupia Wielka and Sulejów (Tab. 1). In 2014, the experiments involved five spring wheat varieties, as well as 10 two-component mixtures and 10 three-component mixtures of these varieties. Compared to monocultures, better yield and healthiness of the stand and grain was found for three-component mixtures, so in the following years experiments included only 20 combinations of three-component mixtures of six varieties.

Description of field experiments

Field experiments were carried out consistently with the methodology used in VCU testing system (COBORU, 2014, 2015). Experiments were established in a unifactorial incomplete one-resolvable block design, in three replicates. Chemical protection

Tabela 1
Table 1

Materiał badawczy

Material

Nazwa odmian Name of varieties	Liczba mieszanek dwuskładnikowych No of two component mixtures	Liczba mieszanek trójskładnikowych No of three component mixtures	Doświadczenie polowe Field trial	
			Lokalizacja Location	Rok zbioru Harvest year
Arabella, Izera, Ostka Smolicka, Struna, Tybalt (5)	10	10	Przecław, Słupia Wielka, Sulejów,	2014
Arabella, Goplana, Harenda, Kamelia, KWS Torridon, Mandaryna (6)	-	20	Przecław, Słupia Wielka, Sulejów	2016
Goplana, Frajda, Nimfa, Harenda, Rusałka, Jarlanka (6)	-	20	Przecław, Słupia Wielka, Sulejów	2018

of plants included the treatment of seeds before sowing, and the use of herbicides and insecticides to control the emerging pests. No chemical treatments were used to protect plants against diseases or lodging. Mineral fertilization differed between individual experimental stations and was adjusted to soil quality, type of forecrop and the abundance of minerals in the soil. The area of a single plot was 15 m^2. When determining the sowing rate, the weight of 1000 kernels and the germination capacity of grain of individual varieties were considered. The sowing rate for all varieties in a pure stand and mixed sowing was 450 grains/m^2. The proportion of each variety in mixtures was the same, 225 grains/m^2 in two-component mixtures, and 150 grains/m^2 in three-component mixtures. Weather conditions, i.e. mean monthly air temperatures and the sum of rainfall in a given year at three locations are presented in Table 2 (COBORU, 2014, 2015; 2016; 2018).

Weather conditions during three growing seasons, when cereal grains were sampled for analyses, varied and certainly influenced the chemical composition of the grain. The growing season in 2014 was characterised by very high rainfall in May (117 mm) and August (119 mm), and high mean air temperatures in July. In 2015, higher rainfall was recorded in July (169 mm) and lower in May (39 mm), and high air temperatures in the summer months. 2018 was characterized by a very dry and cold and then hot early spring. The sum of rainfall in March and April was 35 mm and 20 mm, with mean monthly temperatures of -0.4C° and 14.2C°, respectively. In 2018, high air temperatures with less rainfall persisted throughout the growing season.

Chemical analyses

An analytical sample was prepared in the laboratory by pooling grains of each variety or a variety mixture in equal weight proportions from each of the three harvest locations. Grain samples prepared in this way were ground in a mill (Cyclotec™, Foss) with a sieve, 0.5 mm mesh size. Samples were analysed for the content of dry matter (no. 44–16.01), protein (no. 46–11.02), mineral components (no. 08–01.01) and digestible starch (no. 76–11) using standard methods acc. to AACC (2011), and total lipids by a gravimetric method after acidic extraction according to Marchello et al. (1971). The sum of these four components was the content of nutrients (SSO). Samples were also analysed for the content of Klason lignin and bioactive compounds, such as: non-starch polysaccharides (NSP), divided into soluble (S-NSP) and insoluble (I-NSP) fractions, including β-glucan and arabinoxylans (TAX), divided into water-extractable fraction (WE-AX) and unextractable fraction (WUE-AX), then total polyphenols (TPC) and alkylrecorcinols (AR). NSP was determined by gas chromatography according to Englyst and Cummings (1984), and expressed as the sum of sugars: arabinose, xylose, mannose, galactose and glucose, while β-glucan was determined colorimetrically according to AACC method no. 32-23 (2011). Klason lignin was analyzed by gravimetry as a residue of digestion with 72% sulfuric acid (Theander, Westerlund, 1986). The content of total digestible fibre (TDF) was calculated from the content of NSP and lignin, according to method no. 32-25, AACC (2011). Total

Tabela 2
Tab le 2

Warunki pogodowe w sezonie wegetacyjnym w latach 2014, 2016 i 2018

Weather conditions during growing season in years 2014, 2016 and 2018

Sezon wegetacyjny Growing season	Miesiąc/Month					
	III	IV	V	VI	VII	VIII
Suma opadów*/Rainfall* [mm]						
2014	45	37	117	60	113	119
2016	44	45	39	62	169	45
2018	35	20	53	59	106	53
Średnia temperatura powietrza* / Mean air temperature* [°C]						
2014	6,2	10,2	13,3	15,6	20,4	17,7
2016	5,7	11,2	15,2	19,6	20,4	18,5
2018	-0,4	14,2	16,7	18,6	19,5	20,0

**Wartości średnie z trzech lokalizacji/Mean values from three locations* phenolic compounds (TPC) were determined using the colorimetric method with the Folin-Ciocalteau reagent (Singleton and Rossi, 1965). Results were expressed in milligrams of gallic acid (GAE) equivalent per g of dry sample weight. Alkylresorcinols were extracted from the whole grain with acetone and determined colorimetrically according to Tłuścik et al. (1981) based on a colour reaction with Fast Blue B $ZnCl_2$ diazonium salt measured at 520 nm wavelength (Gajda et al., 2008). Each analysis was performed in at least two replicates, and the error did not exceed 3% for nutrients, and 4% for other analysed compounds. The results were converted to dry matter basis.

Measured values were statistically processed using the ANOVA model, separately for the material from each year of the study (Statistica 13.3). In addition, Pearson's linear coefficients of correlation between selected grain components were calculated, and the level of significance was adopted at $p<0.05$ and $p<0.01$ (results discussed further in the text). The Tukey-Kramer multiple comparison procedure was used for varieties and their mixtures.

Results and Discussion

The research material was selected and prepared for chemical analyses in order to verify the effect of mixed sowing on the nutritional value of the grain for the largest possible number of spring wheat varieties. We analysed the chemical composition of grain from 14 varieties and 60 variety combinations harvested in 2014, 2016 and 2018 from field experiments established each year in three locations. When selecting varieties for mixed sowing, the origin (domestic varieties first), high yield and differences in disease resistance were considered (COBORU, 2014 and 2015; 2016; 2018).

Mean yields of variety mixtures in study years did not differ significantly from the mean yield of varieties grown in monocultures, although in 2014 and 2018 they were much higher than in 2016 (Tab. 3). The unfavourable weather conditions during the growing season probably contributed to the lower yield in 2016 (Tab. 2). Of the analysed varieties and their mixtures, the highest yield in 2014 was obtained for a two-component mixture, Arabella + Struna (75.9 dt per ha), and the lowest (by more than 8 dt per ha) for the Tybalt variety (COBORU, 2014, 2015). In 2016, the highest yields were obtained from Goplana and Harenda (55.9 and 55.6 dt per ha), as well as a mixture of the same two varieties and Mandaryna (57.9 dt per ha), while the lowest yields were obtained for Arabella + Harenda + KWS Torridon and Arabella + Goplana + Kamelia mixtures (slightly more than 53 dt per ha) (COBORU, 2016). In 2018 there were very considerable differences in yields between locations, from 47.5 dt per ha in Sulejów to 85.2 dt per ha in Słupia Wielka. The mean yield was highest for the mixtures of Goplana and Harenda with Frajda and Nimfa (76.9 and 76.3 dt per ha). Yield was also high for Goplana (75.8 dt per ha) grown in a monoculture, but lower for the mixture of Frajda+Harenda+Rusałka (71.4 dt per ha) (COBORU, 2018). Most spring wheat varieties used in mixtures (11 varieties) were class A bread wheat, and another 3 varieties (Frajda, Harenda and Kamelia) represented class B bread wheat (COBORU, 2020).

Tabela 3
Table 3

Plonowanie pszenicy jarej w latach 2024, 2026 i 2018* [dt-ha^{-1}]

Grain yield of spring wheat in 2014, 2016 and 2018* [dt-ha^{-1}]

Rodzaj zasiewu	Rok zbioru/Harvest year		
	2014	2016	2018
Odmiany w siewie czystym Pure variety	71,8	54,8	74,7
Mieszanki dwuskładnikowe Two component mixture	71,8	-	-
Mieszanki trójskładnikowe Three component mixture	72,1	54,8	74,7
Plon średni z 3 lat dla miejscowości Average 3-year yield per location	Przecław	Słupia Wielka	Sulejów
	69,7	76,6	54,0
Zakres w latach Range in years	59,3 – 83,7	55,9 – 88,6	46,4 – 67,8

**Dane COBORU/COBORU data*

Wheat grain is the basic raw material for the milling and baking industry, as well as a valuable component of feed mixtures for all types of livestock. Analysis of basic chemical components, i.e. protein, minerals, lipids and starch making up the sum of nutrients (SSO), provides fundamental information for the determination of the nutritional value of wheat grain and its suitability for milling and baking (Hoseney, 1994). In assessing the processing value of breeding lines and new wheat varieties, an effective preliminary quality criterion is the percentage of protein in the grain, since it corresponds with the yield of wet gluten and thus the baking quality of wheat flour (Cygankiewicz, 1997; Stępniewska, Słowik, 2016). Compared to winter wheat, spring wheat is generally characterized by better baking quality but lower milling quality, which is associated with a higher protein content and a lower starch content (Biel, Maciorowski, 2012; Cacak-Pietrzak et al., 2014; Boros et al., 2015). In contrast, some limited data indicate higher protein content in the grain from winter forms compared to spring forms of wheat (Stępniewska, Słowik, 2016), which is most likely influenced by the selection and number of assessed genotypes, as well as weather conditions during the growing season. In our study we found no significant differences (p>0.05) in SSO between

Tabela 4

Table 4

Zawartości składników odżywczych w ziarnie odmian oraz ich mieszanin odmianowych pszenicy jarej (wartości średnie z poszczególnych lat zbioru, w% s.m.)

Content of nutrients in varieties and their variety mixtures of spring wheat (mean values for particular harvest years, on DM %)

Odmiany, mieszanki Varieties, mixtures	Białko Protein	Lipidy Lipids	Składniki mineralne Minerals	Skrobia Starch	SSO*
2014 rok zbioru / 2014 harvest year					
Odmiany Varieties	13,4±0,4[a]	2,58±0,1	1,58±0,1	65,3±0,5[b]	82,9±0,8
Mieszaniny dwuskładnikowe Two component mixtures	13,4±0,4[a]	2,63±0,1	1,57±0,0	65,6±0,5[ab]	83,2±0,7
Mieszaniny trójskładnikowe Three component mixtures	13,0±0,4[b]	2,61±0,1	1,56±0,1	66,2±0,9[a]	83,4±0,8
Prawdopodobieństwo Probability	0,0001	0,0001	0,0001	0,086	0,059
NIR/LSD	0,301	0,098	0,086	ns	ns
2016 rok zbioru / 2016 harvest year					
Odmiany Varieties	14,3±0,4	2,79±0,1	1,45±0,0	60,8±1,0	79,3±0,7
Mieszaniny trójskładnikowe Three component mixtures	14,3±0,2	2,84±0,1	1,44±0,1	60,3±0,7	78,9±0,7
Prawdopodobieństwo Probability	0,0001	0,0001	0,0015	0,006	0,047
NIR/LSD	0,349	0,255	0,069	2,813	2,943
2018 rok zbioru / 2018 harvest year					
Odmiany Varieties	12,4±0,1[b]	2,60±0,1	1,58±0,1	60,7±1,4[a]	77,3±1,5[a]
Mieszaniny trójskładnikowe Three component mixtures	12,7±0,2[a]	2,62±0,1	1,62±0,1	59,2±1,1[b]	76,2±1,0[b]
Prawdopodobieństwo Probability	0,4659	0,0001	0,0001	0,0033	0,0018
NIR/LSD	ns	0,168	0,117	4,398	3,919

**SSO – suma składników odżywczych; SSO – sum of nutrients* the grain from varieties and their mixtures harvested in 2014 (Tab. 4). However, there were significant differences ($p<0.05$) in SSO between grain harvested in 2016 and 2018. With regard to grain harvested in 2018, there were significant differences in SSO between varieties grown in monocultures and three-component mixtures of these varieties. The grain from three-component mixtures harvested in 2018 contained on average 1.1 percent less SSO compared to the mean value for their components. Overall, grain harvested in 2018 was characterized by the lowest SSO value (76.4%) due to the low content of protein (12.6%) and starch (59.6%) compared to wheat grain harvested in earlier years. The genotype certainly had a strong effect on the differences in protein, starch and, consequently, SSO content in the years of grain harvest. The influence of variable weather conditions during the growing season on differences in the content of basic nutrients is also possible (Lee et al., 2006). Grain from Goplana and Harenda varieties harvested from experimental fields in 2016 and 2018 differed significantly in terms of protein content, even though these varieties were grown on the same type of soil. In the compared years of harvest (2016 and 2018) the content of protein in grain was 13.8% vs. 12.6% for Goplana, and 14.1% vs.12.3% for Harenda. The dry and warm end of April and high temperatures in May 2018 slowed down the development of plants, which probably influenced further growth stages, such as the formation of stems and ears (COBORU, 2018). A similar great difference in the content of protein was recorded for grain from Arabella harvested in 2014 and 2016, which was 13.3% vs. 14.6%, respectively. In general, significant differences were found in the protein content in grain from varieties and mixtures harvested in 2014 and 2018, and in the content of starch in grain harvested in 2016 and 2018. Moreover, there were significant differences between varieties and their mixtures in the content of protein and starch in grain harvested in 2014 and 2018, but not in grain harvested in 2016. Considering the set of grain samples from 2014, three-component mixtures were characterised by a lower mean content of protein (13.0% vs. 13.4%), but a higher content of starch (66.2% vs. 65.4%) compared to the mean content of these compounds in two-component mixtures or pure varieties. In 2014 the highest content of protein in grain was found for Arabella+Tybalt and Izera+Tybalt (13.8% for each mixture). The content of protein was highest in Ostka Smolicka (13.8%) and lowest in Izera (12.7%). Grain harvested in 2016 was characterised by a high content of protein (mean 14.3%), but a low content of starch (mean 60.5%). The content of protein was highest in Kamelia, KWS Torridon and Arabella (14.7% to 14.6%), and in their tree-component mixture (14.7%). The mixture of varieties with the lowest content of protein (less than 14%), i.e. Goplana, Harenda and Mandaryna, contained the lowest amount of protein (13.9%) considering all mixtures harvested in 2016. In grain harvested in 2018 there were minor differences in the content of protein (1%) between varieties and their mixtures. The content of protein was highest for Goplana, Jarlanka and Nimfa varieties (12.6%), and for the mixture of Jarlanka and Nimfa with Harenda (13.1%), with Goplana, and with Frajda (12.9% for each combination). Studies analysing, for example, the processing quality of grain from four spring wheat varieties grown in pure and mixed stands in 1996-1998 revealed no significant differences in the protein content between varieties and their mixtures (Żmijewski, 2004). Considering protein content as one of the basic determinants characterizing the baking quality of wheat, it can be concluded that the grain from each of the tested variety mixtures, as well as from each pure variety, met the requirements established for raw material. According to Rothkaehl (2015), grain to be used for processing into baking flours should contain at least 11.5% of protein in dry matter. In our study, a negative correlation between the content of protein and starch was found in each year (Tab. 6). These correlations were significant in relation to grain harvested in 2016 and 2018 ($r = -0.524$ and $r = -0.450$). Similar relationships between the two components of grain were obtained for another combination of winter wheat and spring wheat varieties (Boros et al., 2014), as well as for samples of wheat flour available on retail sale and those prepared in a laboratory (Achremowicz et al., 2010). The negative correlation between the protein and starch content in cereal grains has been known for a long time and results from the differences in energy expenditure associated with the synthesis of these compounds. Cereal plants need more than twice as much energy for protein synthesis as for starch synthesis, expressed in glucose units, and amounts to 2.5 and 1.2, respectively (Munck, 1987). Starch, the main storage compound in cereal grains, is an excellent source of energy in food or feed, and its hydrolysis plays a significant role during the baking process (Hoseney, 1994). The starch content in the analysed three-component variety mixtures ranged from 56.6% (Goplana + Jarlanka + Rusałka in 2016) to 67.4% (Izera

+ Ostka Smolicka + Struna mixture in 2014), with mean values of 66.2%, 60.3% and 59.2% for individual years of the study. Grain from three-component mixtures harvested in 2014 contained on average significantly more starch than grain from monocultures (66.2% vs. 65.3%). Inverse relationships were found for grain harvested in 2018, and the mean content of starch in variety mixtures was significantly lower (59.2%) compared to grain from monocultures (60.7%). No such relationships were found for grain harvested in 2016.

Wheat grain is an important source of dietary fibre and other substances with health-promoting properties in the human diet (Shewry et al., 2010; Jones, 2010). Dietary fibre is a complex of heterogeneous substances resistant to digestive enzymes

Tabela 5

Table 5

Zawartość włókna pokarmowego i jego składników w ziarnie odmian oraz ich mieszanin odmianowych dwu i trójskładnikowych pszenicy jarej (wartości średnie z poszczególnych lat zbioru, w% s.m.)

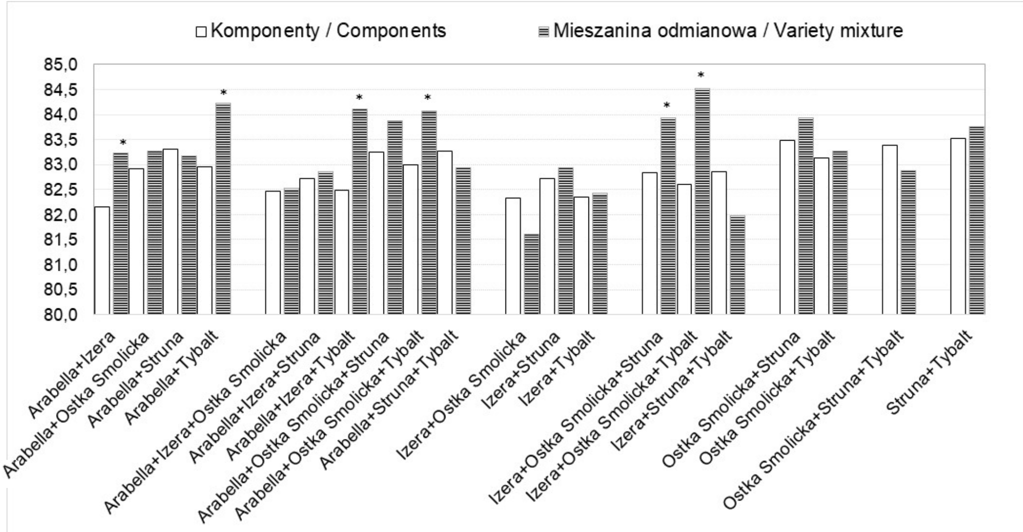
Content of nutrients in varieties and their variety mixtures of spring wheat (mean values for particular harvest years, on DM %)

Odmiany, mieszanki Varieties, mixtures	S-NSP	I-NSP	NSP	Lignina Lignin	TDF	WE-AX	WUE-AX	TAX	β-glukan β-glucan
2014 rok zbioru / 2014 harvest year									
Odmiany Varieties	2,10±0,2	7,07±0,5	9,17±0,6	2,87±0,1[ab]	12,0±0,5	1,11±0,2	4,20±0,3	5,31±0,4	0,73±0,1
Mieszaniny dwuskładnikowe Two component mixtures	2,02±0,2	7,24±0,5	9,26±0,5	2,71±0,2[b]	12,0±0,6	1,08±0,1	4,39±0,3	5,47±0,3	0,72±0,0
Mieszaniny trójskładnikowe Three component mixtures	1,97±0,1	6,96±0,3	8,93±0,4	3,08±0,3[a]	12,0±0,4	1,06±0,1	4,19±0,2	5,25±0,2	0,75±0,1
Prawdopodobieństwo Probability	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001
NIR/LSD	0,283	0,735	0,803	0,330	0,822	0,187	0,601	0,625	0,061
2016 rok zbioru / 2016 harvest year									
Odmiany Varieties	2,27±0,2[a]	6,53±0,6	8,80±0,5	3,18±0,4	12,0±0,8	1,17±0,1[a]	3,96±0,3	5,13±0,3	0,69±0,0
Mieszaniny trójskładnikowe Three component mixtures	2,10±0,1[b]	6,82±0,6	8,92±0,6	3,13±0,3	12,0±0,7	1,05±0,1[b]	4,18±0,3	5,23±0,3	0,69±0,0
Prawdopodobieństwo Probability	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001
NIR/LSD	0,177	0,428	0,419	0,256	0,520	0,123	0,321	0,319	0,087
2018 rok zbioru / 2018 harvest year									
Odmiany Varieties	2,01±0,2	6,86±0,6[b]	8,87±0,5[b]	3,30±0,4	12,2±0,8	0,88±0,1	4,24±0,3[b]	5,13±0,2[b]	0,66±0,0
Mieszaniny trójskładnikowe Three component mixtures	2,03±0,2	7,57±1,0[a]	9,60±1,1[a]	3,02±0,5	12,6±1,1	0,89±0,1	4,50±0,4[a]	5,40±0,4[a]	0,64±0,0
Prawdopodobieństwo Probability	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001
NIR/LSD	0,222	0,662	0,752	0,314	0,903	0,071	0,354	0,371	0,096

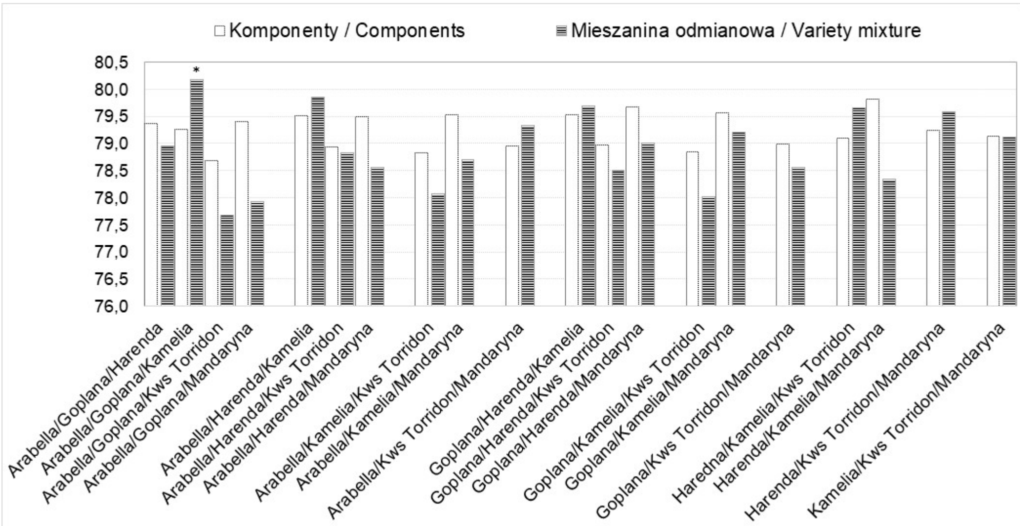
S-NSP – rozpuszczalne nieskrobiowe polisacharydy/soluble nonstarch polysaccharides; I-NSP – nierozpuszczalne nieskrobiowe polisacharydy/insoluble nonstarch polysaccharides; NSP – nieskrobiowe polisacharydy/nonstarch polysacchrides; TDF – włókno pokarmowe ogółem/total dietary fibre; WE-AX – arabinoksylany ekstrahowalne w wodzie/water extractable arabinoxylans; WUE-AX – arabinoksylany nieekstrahowalne w wodzie/water unextractable arabinoxylans; TAX – arabonoksylany ogółem/total arabinoxylans present in the human digestive tract. From a chemical point of view, dietary fibre includes non-starch polysaccharides, which in the case of wheat are mainly arabinoxylans, in addition to oligosaccharides, resistant starch, uronic acids and lignin. Wheat grain contains only small amounts of oligosaccharides, uronic acids and resistant starch, and therefore their determination was omitted in this study. The obtained results showed relatively large and significant differences between varieties in the content of TDF and its components in grain harvested in different years (Tab.5). The greatest differences were found in the content of arabinoxylans, particularly in their water-extractable fraction. The coefficients of variation for this component of dietary fibre were 15%, 9% and 13%, respectively, in the grain harvested in 2014, 2016 and 2018. Differences in the content of TDF and its components in the grain from monocultures had a significant impact on the content of these compounds in mixtures. Although in general the mean values for TDF were similar across the study years (12.0-12.6%), there were significant differences in the TDF content in the grain from each harvest year. Similar significant differences were found in each year of the study for individual fibre components: S-NSP, I-NSP, NSP, lignin, as well as arabinoxylans and β-glucan. Grain from Arabella and Ostka Smolicka harvested in 2014 contained significantly more TDF (12.6%) than Struna and Tybalt (11.5%). Considering three-component mixtures, eight had significantly more TDF (12.5%) than the mixtures of Izera and Struna with Arabella or with Ostka Smolicka (11.2%) (Fig. 1). In 2016, the content of TDF in grain was highest for KWS Torridon (13.1%) and lowest for Arabella and Harenda (10.9% and 11.0%). In other wheat varieties the content of TDF was from 12.1% to 12.4%. The content of TDF was lowest in the mixture of Arabella+Harenda+Kamelia (10.8%), and highest (13.4%) in the mixture of Harenda+Goplana+Kamelia and Goplana+Kamelia+KWS Torridon. In 2018 the content of TDF in grain was highest (13.0%) for Frajda and Nimfa, lower for Jarlanka (12.5%), Goplana (12.3%) and Harenda (11.7%), and lowest for Rusałka (10.7%). The mixture of varieties with the highest content of TDF (Frajda+Goplana+Nimfa) contained the highest amount of TDF (15.0%). The list of mixtures with the highest content of TDF also included those with Frajda and Jarlanka (14.3%), or Frajda and Goplana (13.8% to 14.4%). The lowest content of TDF was found in mixtures composed with Rusałka and Harenda (11.5%-12.1%), which are varieties with a significantly lower content of TDF. Each of the determined fibre components influenced differences in the content of TDF in the grain from varieties and their mixtures. The content of non-starch polysaccharides (NSP), whose share in the total amount of fibre was the highest (73% to 77%), had the largest effect on these differences. The correlation coefficients between the content of TDF and the content of NSP in the grain were highly significant ($p<0.01$) and amounted to $r=0.812$; $r=0.885$ and $r=0.894$ for individual harvest years (Tab. 6). Arabinoxylans, the main polysaccharide components of wheat grain, with an almost 50% share in TDF, ranging from 43% to 46% in grains of varieties and mixtures, also had a significant influence on the differences in TDF content. The correlation coefficients between the TDF content and the TAX content were $r = 0.800$ for grain harvested in 2014 and 2018, and $r=0.866$ for grain harvested in 2016. The results obtained in this study with regard to the content of dietary fibre, its main components, as well as differences, are similar to those reported by other authors who analysed a range of variety combinations grown for grain under different conditions (Bach Knudsen, 2014; Boros et al., 2015).

Whole grain products in the human diet provide fibre, but also many biologically active substances, including polyphenols and alkylresorcinol (Vitaglione, Fogliano, 2010). For this reason, Jones (2010) defined them as dietary fibre's co-passengers. In plants, they are essential for growth and development, adaptation to biotic and abiotic stress, and defence against these stressors. In food, they are responsible for colour, taste, flavour and antioxidant, anti-inflammatory, antibacterial, antihypertensive, immunostimulating, hypocholesterolic and anticancer properties (Jones, 2010; Vitaglione, Fogliano, 2010). Cereals are the main source of biologically active substances in the human diet (Jones, 2010). Our study showed significant differences in the content of total phenolic compounds (TPC) and alkylresorcinols (AR) in the grain from wheat varieties harvested each year (Tab. 7). In 2014 the content of TPC was in the range of 1.1–1.4 mg/g, and AR 470–570 mg/g of grain, with the coefficient of variation equal to 10% and 6%. Ostka Smolicka and Izera contained significantly more TPC and AR, 1.5 mg/g and 570 mg/g, respectively, compared to other wheat varieties. The content of TPC and AR was

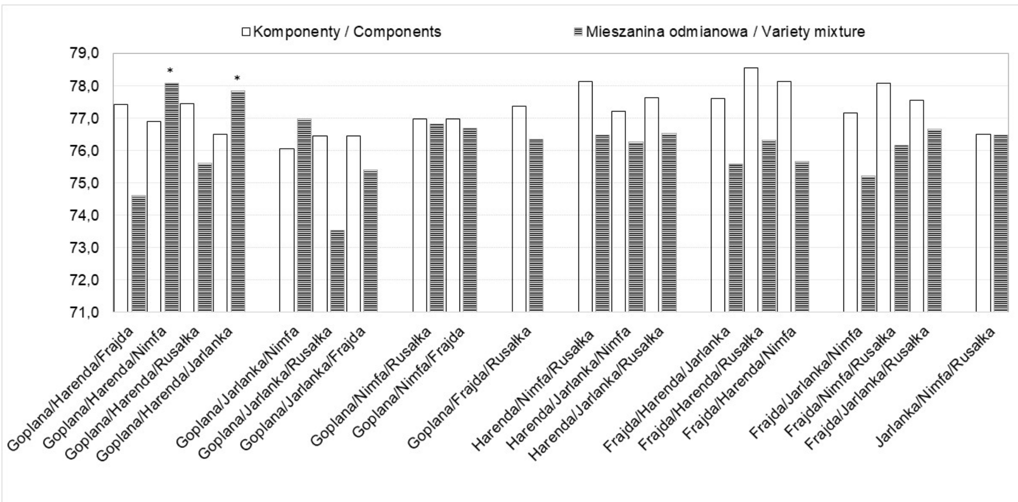
A.



B.



C.



**różnica istotna / *significant difference*

Rys. 1. Porównanie sumy składników odżywczych w ziarnie odmian-komponentów z siewu czystego i w mieszaninach dwu i trójskładnikowych z ich udziałem ze zbioru w latach A. 2014; B. 2016 i C. 2018 (dla komponentów - wartość średnia odmian)

Fig. 1. Comparison of the nutrient contents in pure varieties and in their two or three component mixtures from harvest in years A. 2014; B. 2016 and C. 2018 (for component - varieties average value)

higher in grain harvested in 2016 (1.3–1.9 mg/g, and 400–680 mg/g of grain), with variations of 17% and 18%, respectively. The highest content of TPC (1.9 and 1.8 mg/g) was found in Goplana and Kamelia, and the highest content of AR (680 and 610 mg/g) in Kamelia and KWS Torridon. In 2018, grain harvested from varieties contained very similar levels of TPC and AR (1.3–1.5 mg/g and 440–490 mg/g), and thus the variation in these traits was low, 4% and 3%, respectively. Grain from varieties harvested in 2018 did not differ significantly for the content of TPC, and the highest content of polyphenols was found in Rusałka. The content of AR in grain was significantly higher for Frajda than for Goplana (455 mg/g), Harenda (452 mg/g) or Rusałka (441 mg/g). Due to the small amounts of phenolic compounds in the grain of wheat varieties grown in monocultures, despite sometimes large variation within the tested material, it is difficult to clearly indicate whether their level in varieties influenced the content of both TPC and AR in the grain from variety mixtures. Grain from variety mixtures harvested in 2018 contained on average significantly more TPC (1.46 mg / g), including alkylresorcinols (494 mg/kg), than the grain from varieties used as components of these mixtures containing the above-mentioned phenolic compounds in amounts of 1.40 mg/g; 459 mg/ kg. On the contrary, in variety mixtures harvested in 2014 the content of both phenolic compounds in the grain was lower, and in the case of AR the difference was significant (522 vs. 452 mg/ kg). We found no significant differences between the mean values for varieties grown in monocultures, or the mean values for variety mixtures in the content of phenolic compounds in grain harvested in 2016. Levels of phenolic compounds measured in our study are consistent with those reported by other authors for spring wheat varieties (Vitaglione, Fogliano, 2010; Boros et al., 2015).

The genetic diversity in the content of dietary fibre and its components indicates that the selection of varieties can modify both the amount and composition of TDF in spring wheat varietal mixtures. The appropriate selection of varieties will enable the production of grain that meets the requirements of the cereal, milling and baking industries, with improved health-promoting properties, and on the other hand, high-quality grain for the feed industry, with a high content of nutrients and a reduced content of antinutrients. The TDF complex, which is not digested in the gastrointestinal tract if present in an excessive amount in the feed, in particular the content of water-extractable arabinoxylans, contributes to reduced feed intake, reduced digestibility and bioavailability of nutrients, and leads to a deterioration of the performance parameters in the livestock (Choct, Annison, 1992). Therefore, it is considered an antinutrient in feed for non-ruminant animals, since animal production is strongly focused on profitability.

The presented research shows that certain combinations of varieties may utilize environmental resources more efficiently than their monocultures. This results not only in a higher grain yield of varietal mixtures, but also their functional value. The cultivation of variety mixtures can potentially increase the functional value and resistance of spring wheat grain, and therefore the identification of an appropriate combination of genotypes in this respect requires further and more detailed research.

Tabela 6
Table 6

Współczynniki korelacji r-Pearsona między wybranymi składnikami ziarna pochodzącego z trzech lat zbioru

Person's correlation coefficients of grain components in three years of harvest

Składniki porównywane Components compared	Rok zbioru / Harvest year		
	2014	2016	2018
Białko - skrobia / Prptein - starch	-0,316	-0,524*	-0,450*
I-NSP – TDF	0,761**	0,835**	0,890**
S-NSP – TDF	0,382	-0,083	0,112
NSP – TDF	0,812**	0,885**	0,894**
TAX – TDF	0,800**	0,866**	0,799**

I-NSP – nierozpuszczalne nieskrobiowe polisacharydy/insoluble nonstarch polysaccharides; S-NSP – rozpuszczalne nieskrobiowe polisacharydy/soluble nonstarch polysaccharides; NSP – nieskrobiowe polisacharydy/ nonstarch polysacchrides; TDF – włókno pokarmowe ogółem/total dietary fibre; TAX – arabonoksylany ogółem/ total arabinoxylans
**Istotny przy p<0,05/Signifcant at p<0,05; **Istotny przy p<0,01; Signifcant at p<0,01*

Conclusions

1. Most of the intraspecific spring wheat mixtures yielded higher than their components grown in monocultures and were characterized by better plant health. This indicates that variety mixtures use environmental resources more efficiently than individual varieties grown in monocultures.
2. The overall analysis of grain for chemical composition showed that the nutritional value of grain can be improved through the cultivation of spring wheat variety mixtures.
3. Genotypes significantly influenced the content of nutrients and the dietary fibre complex in the grain of spring wheat variety mixtures. Identification of suitable varieties for mixed sowing is necessary to improve the nutritional value of grain from spring wheat.
4. The suitability of spring wheat varieties for mixed sowing should be assessed in a comprehensive fashion by combining data from field evaluation and analyses of the chemical composition of grain.

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Tabela 7

Table 7

Zawartość związków fenolowych ogółem (TPC), w tym alkilorezorcynoli w ziarnie odmian i ich mieszanin odmianowych pszenicy jarej (wartości średnie z poszczególnych lat zbioru)

Content of total phenolic compounds (TPC) and alkylresorcinols in varieties and variety mixtures of spring wheat (mean values of particular harvest years)

Odmiany, mieszanki Varieties, mixtures	TPC [mg GAE/g s.m.] [mg GAE/g DM]	Alkilorezorcynole [mg/kg] Alkylresorcinols [mg/kg]
2014 rok zbioru/2014 harvest year		
Odmiany Varieties	1,33±0,1	522±33[a]
Mieszaniny dwuskładnikowe Two component mixtures	1,26±0,1	491±25[a]
Mieszaniny trójskładnikowe Three component mixtures	1,27±0,1	452±41[b]
Prawdopodobieństwo Probability	0,0001	0,0001
NIR/LSD	0,203	40,2
2016 rok zbioru/2016 harvest year		
Odmiany Varieties	1,55±0,2	574±94
Mieszaniny trójskładnikowe Three component mixtures	1,54±0,1	595±70
Prawdopodobieństwo Probability	0,0001	0,0001
NIR/LSD	0,123	54,1
2018 rok zbioru/2018 harvest year		
Odmiany Varieties	1,40±0,0[b]	459±0,1[b]
Mieszaniny trójskładnikowe Three component mixtures	1,46±0,1[a]	494±0,1[a]
Prawdopodobieństwo Probability	0,0042	0,0001
NIR/LSD	0,222	31,6

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