Journal of Elementology ISSN 1644-2296

Wanic M., Denert M., Treder K. 2019.
Effect of forecrops on the yield and quality of common wheat and spelt wheat grain.
J. Elem., 24(1): 369-383. DOI: 10.5601/jelem.2018.23.1.1585

RECEIVED: 26 February 2018
ACCEPTED: 21 August 2018

ORIGINAL PAPER

EFFECT OF FORECROPS ON THE YIELD AND QUALITY OF COMMON WHEAT AND SPELT WHEAT GRAIN

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Abstract

Owing to the quality values of its grain, spelt wheat has become an increasingly often cultivated cereal not only in bio-farming but also in other systems of agriculture. The aim of this study was to compare the yield and quality of grain of common wheat and spelt wheat grown on plots after winter oilseed rape, pea, and after wheat/spelt wheat. The research was based on a field experiment carried out in Bałcyny (Poland). Two experimental factors were investigated: 1. Subspecies of winter wheat: common wheat and spelt wheat; 2. Cultivation of these cereals after winter oilseed rape, pea, and after winter wheat/spelt wheat. Results presented in this manuscript originate from years 2013-2015. The following determinations were performed on the grain each year: grain yield, contents of protein, wet gluten and starch, sedimentation index, falling number and contents nutrients. The yield of spelt wheat grain was by over 20% lower than that of common wheat grain. Its grain contained more protein, wet gluten, Ca, Mg and Zn, and less starch K and Fe. Grain yield of both cereals was positively affected by winter oilseed rape and negatively by wheat/spelt used as the forecrop. Their culture after pea significantly increased protein content of their grain, and also wet gluten content in the case of spelt wheat grain. In common wheat grain from a rotation plot in succession (wheat after wheat), values of these parameters were lower than in common wheat grain harvested after pea and oilseed rape. The forecrops had no effect on the other technological parameters of the grain of both cereals and on the P, K, Mg, Ca, and Cu content in the grain. Grain of common wheat grown after oilseed rape contained more Fe, and grain of wheat grown after pea had more Zn than after the other forecrops. Grain of spelt wheat from the plot after pea had a higher content of Mn, and that of spelt wheat from succession plot had less Fe.

Keywords: common wheat, spelt wheat, forecrops, technological quality, elements.

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INTRODUCTION

Common wheat (*Triticum aestivum* ssp. *vulgare* L.) has become the most popular cereal grown worldwide owing to its high yielding and to the quality traits of its grain. Advance in breeding has led to the development of novel cultivars adjusted to various habitat conditions, different cultivation technologies and potential applications as well as being resistant to some pathogens and pests. Due to concerns over human health, biodiversity and homeostasis in the natural environment, a return is observed to old subspecies of this cereal like spelt, emmer, einkorn, or millet (Escarnot et al. 2012, Biel et al. 2016). Out of these, the greatest interest has been aroused by spelt wheat (*Triticum aseativum* ssp. *spelta* L.) including both its old cultivars (e.g. Schwabencorn) and newly emerging ones (Filipčev et al. 2013, Sobczyk et al. 2017).

Wheat is a species sensitive to the choice of forecrops and frequency of crop rotations (Blecharczyk et al. 2006, Jaskulska et al. 2013). Its cultivation after inappropriate forecrops and especially their succession, upsets the balance in the soil ecosystem which is referred to as "soil tiredness" (Gawrońska 1997). This leads to increased weed infestation and to crop infestation by pathogens and pets. Such conditions result in decreased plant density in the field, suppressed crop growth and in lower grain yield with poorer quality parameters (Kaczmarska, Gawrońska-Kulesza 2000, Woźniak 2006). Although there are numerous studies on the response of common wheat to the selection of forecrops, little information is available in this respect regarding spelt wheat.

The aim of this study was to determine the effect of two subspecies of winter wheat (common and spelt) and forecrops (winter oilseed rape, pea, winter wheat/spelt) on the yield and quality of their grain.

MATERIAL AND METHODS

The study was based on a controlled static field experiment carried out since autumn of 2011 at the Production and Experimental Plant in Bałcyny (53°35′46″ N 19°51′18″ E), owned by the University of Warmia and Mazury in Olsztyn (Poland). Results presented in this manuscript concern a 3-year period (2013-2015), which represented the 2nd, 3rd and 4th year of the experiment. Soil on the experimental fields was classified as typical lessive soil, composed of light loams containing 26% of the fine dust fraction and clay fraction. It is characterized by a slightly acidic pH value (pH KCl 5-8-6,5), $C_{org.}$ content of 8.6-9.3 g kg^{-1}, total N content of 0.80-0.85 g kg^{-1}, content of available forms of: P at 57.2-79.4 mg kg$^{-1,}$ (medium to high), K at 9.46-136.1 mg kg^{-1} (medium to high), Mg at 33.6-45.6 mg kg^{-1} (low); total Ca content of 110-1200 mg kg^{-1}, total Cu content of 5.15-5.26 mg kg^{-1}, total Fe content of 3250-3480 mg kg^{-1}, total Zn content of 12.7-13.0 mg kg^{-1}, and total Mn content of 132.3-139.8 mg kg^{-1}.

Experimental factors:

I. Subspecies of winter wheat: common wheat and spelt wheat.

II. Forecrops for common wheat and spelt wheat: winter oilseed rape, pea, winter common wheat/spelt wheat.

The following cultivars were used in the experiment: common wheat cv. Muszelka, spelt wheat cv. Rokosz, winter oilseed rape cv. SY Kolumb, and pea cv. Batuta.

The experiment was established in 4 replications, with all crops (forecrop – main crop) at the same time. The crops were cultivated in a two-year crop rotation system, in which each of the crops returned on the same plot after one-year break. Cereals were sown on optimal agrotechnical dates (autumn: year 2012 – 17 September; 2013 – 21 September; 2014 – 18 September), at the sprouting grain density of 450 grains m^{-2}.

Doses of mineral fertilizers NPK were established in the experiment based on the content of the nutrients in the soil, expected grain yield, forecrop used, and weather conditions. Each year in the springtime before the plant growth was resumed, the content of mineral N was determined in the soil (0-60 cm), and its values were as follows: in 2013 on plots after oilseed rape and after wheats: 10.0-10.5 mg kg^{-1} and after pea: 16.9 mg kg^{-1}, in 2014 on plots after oilseed rape and after wheats: 12.3-13.0 mg kg^{-1} and after pea: 14.6 mg kg^{-1}, and in 2015: 11.2-11.5 mg kg^{-1} and 14.5-15.3 mg g^{-1} after the aforementioned crops, respectively. These values served to establish a suitable N dose, which in the years 2014 and 2015 reached 160 kg ha^{-1} on plots after oilseed rape, common wheat and spelt wheat; and 140 kg kg ha^{-1} on plots after pea. In the year 2013, its dose was reduced to 150 kg ha^{-1} on plots after oilseed rape and wheats, and to 130 kg ha^{-1} on plots after pea. Doses of P and K did not change depending on the forecrop and reached: 35.2 kg ha^{-1} and 91.3 kg ha^{-1}, respectively. Phosphorus (in the form of superphosphate 40% P_2O_5) and potassium (potassium salt 60% K_2O) were used in the autumn, before sowing the cereals. The nitrogen dose (ammonium nitrate NH_4NO_3 34%) was divided into 4 portions, which were applied before sowing (20 kg ha^{-1}), at the tillering stage – BBCH 25-29 (80 kg ha^{-1}), at the shooting stage – BBCH 30-31 (40 kg ha^{-1}), and at the heading stage – BBCH 51-52 (20 kg ha^{-1}). On the plot after pea, nitrogen doses applied in the respective growth stages were as follows: 20, 60, 20, and 20 kg ha^{-1}.

In the studied period, the sum of atmospheric precipitation from September to July reached: 461.6 mm in the years 2012/2013, 406.7 mm in 2013/2014, and 376.0 mm in 2014/2015. It was lower than in the longitudinal period by 12.3%, 22.7% and 28.5%, respectively. In the season of 2012/2013, September and December and the period from March until June were more arid were, whereas in the years 2013/2014 and 2014/2015 – October, November, February and May were drier, and in the season of 2013/2014 – July, and in 2014/2015 – September and June has less rainfall. In contrast, water excess was recorded in July of 2012/2013. Air temperature in the season of 2012/2013 was close to the multi-year average, whereas in seasons of 2013/2014 and 2014/2015 it was higher (by 1.3 and 0.9°C, respectively). Once the plants started to grow after winter (in March), the following months turned out to be warm: May and June of 2013, March, April and July of 2014, and March of 2015. The plant growth of both wheats was negatively affected by: water deficit from March until June and water excess in July of 2012/2013, drought in May and July of 2013/2014, and scarce rains in May and June of 2014/2015.

Wheats were harvested at the stage of full grain maturity (BBCH 89). Grain was dried to the water content of 12% and weighed. At the laboratory, the grain was analyzed for the mass of 1000 grains and for the content of protein, starch and wet gluten; Zeleny's sedimentation index and falling number were determined using a NIR System Infratec™ 1241 Analyzer (Foss). In turn, at the laboratory of Chemical and Agricultural Station in Olsztyn, the grain was determined for the content of: phosphorus (spectrophotometric method), potassium (flame photometry method) as well as magnesium, calcium, iron, zinc and calcium manganese (flame atomic absorption spectrometry F-AAS).

Results were developed statistically by using the multi-way analysis of variance ANOVA, at the level of significance $p < 0.05$, and identifying homogenous groups with the Tukey's test (HSD). In addition, simple correlations between the grain yield and grain traits and between the thousand grain weight and grain traits were calculated using the Pearson's coefficient. Analyses were carried out using Statistica 12.5 software.

RESULTS AND DISCUSSION

Considering all study years and forecrops, spelt wheat grain yield was on average by 22.2% lower compared to common wheat grain yield (Table 1). The least differences between spelt wheat and common wheat in grain yield occurred in 2014 (6.5%). In the other two years, they were greater (*ca* 30%).

Considering all study years, on average, oilseed rape turned out to be the best forecrop for both cereals. Compared to oilseed rape, a slightly lower, by *ca* 3% (but significant), yield was obtained for grain after pea, whereas a significantly lower one for grain from the succession of common wheat and spelt wheat after themselves (by almost 10 and 16%). In 2013, pea appeared to be a better forecrop for both cereals compared to oilseed rape, but in the two successive years, it was inferior to it. Common wheat and spelt wheat responded negatively to their succession after themselves. A decrease in their grain yields on the plot with succession compared to the plot after

Table 1

The grain yields of common wheat and spelt wheat (t ha^{-1})

Cereals	Years	Forecrops			Mean
		oilseed rape	pea	wheat /spelt	
Common wheat	2013	8.52^{b}	9.46^{a}	8.05^{cd}	8.68^{a}
	2014	7.89^{de}	7.15^{gh}	6.99^{h}	7.34^{c}
	2015	8.35^{bc}	7.48^{defg}	7.25^{fgh}	7.69^{b}
	mean	8.25^{a}	8.03^{b}	7.43^{c}	7.90^{a}
Spelt wheat	2013	6.12^{jk}	6.88^{hi}	5.76^{jkl}	6.25^{e}
	2014	7.65^{def}	6.53^{ij}	6.41^{j}	6.86^{d}
	2015	5.93^{kl}	5.63^{l}	4.43^{l}	5.33^{f}
	mean	6.57^{d}	6.35^{e}	5.53^{f}	6.15^{b}

a-l – values marked with the same letter do not differ significantly ($p < 0.05$)

oilseed rape was similar in 2013 (*ca* 6%), while in 2014 it grew to 11.4% in the case of common wheat and to 16.2% in the case of spelt wheat, to finally reach 13.2% for common wheat and 25.3% for spelt wheat in 2015. These results justify the conclusion that the effect of forecrops on changes in grain yield of these cereals was more tangible under less favourable weather conditions (rain deficit, higher air temperature) than under favourable ones. Also, Rozbicki et al. (2015) proved that environmental conditions (climate conditions in particular) exerted a significantly greater effect on common wheat grain yield than agrotechnical measures did. Oilseed rape and pea are considered good forecrops for winter wheat. They ensure good soil culture with the soil being rich in nutrients, especially nitrogen (Kaczmarska, Gawrońska-Kulesza 2000, Jaskulska et al. 2013). In addition, decomposition of post-harvest residues of oilseed rape results in the release of compounds (e.g. glucosinolates) to the soil, which stimulates the growth of microorganisms antagonistic to fungal pathogens of cereals (Kaczmarska and Gawrońska-Kulesza 2000). In turn, even one-time succession of wheat after itself decreases the yield of its grain, which was confirmed in our study and in the investigations conducted by Woźniak (2006) and Jaskulska et al. (2013). This results mainly from the upset balance in the soil environment because of unfavourable changes in the composition and structure of soil microorganisms and accumulation of detrimental secondary metabolites. Consequences include crop thinning, poorer growth and development of plants, reduced uptake of biogenes, increased infestation with pathogens (which attack mainly stem base), and weed spreading (Gawrońska 1997). Our experiment demonstrated a stronger response of spelt wheat than of common wheat to this system of culture. Discussion of this finding is, however, difficult considering a lack of investigations on this subject.

The mass of 1000 grains of common wheat was significantly higher than that of spelt wheat in all study years (Table 2). Considering average for

Table 2

Mass of 1000 grains of common wheat and spelt wheat (g)

Cereals	Years	Forecrops			Mean
		oilseed rape	pea	wheat /spelt	
Common wheat	2013	42.1^{cd}	44.1^{b}	39.1^{de}	41.8^{a}
	2014	45.7^{b}	46.3^{ab}	45.8^{b}	45.9^{a}
	2015	45.3^{b}	47.4^{a}	44.6^{b}	45.8^{a}
	mean	44.4^{a}	45.9^{a}	43.2^{b}	44.5^{a}
Spelt wheat	2013	37.9^{f}	40.1^{de}	38.6^{f}	38.9^{b}
	2014	41.9^{c-e}	43.9^{c}	40.6^{de}	42.1^{b}
	2015	42.0^{cd}	43.6^{c}	42.6^{cd}	42.7^{b}
	mean	40.6^{b}	42.5^{a}	40.6^{b}	41.2^{b}

a-f – values marked with the same letter do not differ significantly ($p < 0.05$)

years, the accuracy of common wheat grain was positively influenced by its cultivation after oilseed rape and pea. In these cases, grain mass was significantly higher than in the case of wheat cultivated after itself. In turn, spelt wheat developed grain with the highest mass when grown after pea. The mass of 1000 grains of common wheat cultivated after pea was higher than after the other forecrops in the years 2013 and 2015. In the year 2014, its values were similar in common wheat cultivated after all previous crops tested. In the case of spelt wheat, grain with a significantly higher mass was produced in the crop grown after pea in 2013, whereas grain with a significantly lower mass when spelt wheat was cultivated after itself than after pea in 2014 year. On the other plots and in the other study years, values of 1000 grain mass were similar.

Compared to wheat grain, spelt wheat grain had a significantly higher content of protein (by 15.1%) and wet gluten (by 12.4%), and a lower content of starch (by 1.4%) – Table 3. It was also characterized by higher values of the sedimentation index (by 46.2%) and falling number (by 32.2%). The higher protein content in the grain of spelt wheat than in common wheat grain was also demonstrated in studies conducted by Krawczyk et al. (2008) and Frakolaki et al. (2018). In turn, literature data on the content of gluten – which is the key characteristic of flour quality – are not that explicit. For instance, Pruska-Kedzior (2008), Filipčev et al. (2013) and Sobczyk et al. (2017) demonstrated that both old and novel cultivars of spelt wheat contained more gluten than wheat, but according to Krawczyk et al. (2008) they have the same or higher content of gluten. Opposite results were achieved by Frakolaki et al. (2018). However, the baking value of spelt wheat gluten is lower because of the preponderance of gliadin fraction over glutenin fraction (Filipčev et al. 2013, Sobczyk et al. 2017). As a consequence, the flour from spelt wheat grain is characterized by greater softening (causing dough extensibility) and by lesser elasticity (Sobczyk et al. 2017), which makes

Table 3

Some technological parameters of common wheat grain and spelt wheat grain

Parametres	Cereals	Forecrops												Mean
		oilseed rape				pea				wheat or spelt				
		years			mean	years			mean	years			mean	
		2013	2014	2015		2013	2014	2015		2013	2014	2015		
Protein (g kg^{-1})	*C**	105.3^{c}	96.0^{c}	100.1^{c}	100.4^{d}	115.0^{b}	109.5^{b}	102.5^{c}	109.0^{c}	106.5^{c}	97.3^{c}	99.5^{c}	101.1^{d}	103.5^{b}
	*S**	118.1^{b}	115.8^{b}	120.3^{b}	118.1^{b}	122.8^{a}	122.0^{a}	127.0^{a}	123.9^{a}	113.7^{b}	112.0^{b}	120.3^{b}	115.3^{b}	119.1^{a}
Starch (g kg^{-1})	*C*	679.3^{c}	665.8^{c-g}	736.3^{a}	693.8^{a}	676.5^{cde}	657.3^{g}	734.5^{a}	689.4^{a}	677.8^{cd}	663.0^{efg}	733.0^{a}	691.3^{a}	691.5^{a}
	S	673.7^{c-f}	658.5^{g}	717.0^{b}	683.1^{b}	663.8^{efg}	664.3^{d-g}	713.0^{b}	680.4^{b}	669.3^{c-g}	661.0^{fg}	718.0^{b}	682.8^{b}	682.1^{b}
Wet gluten (g kg^{-1})	*C*	225.5^{c-h}	211.0^{f-i}	216.0^{d-i}	217.5^{bc}	250.0^{a}	204.0^{hi}	214.3^{e-i}	222.8^{b}	211.1^{f-i}	201.0^{i}	207.2^{ghi}	206.4^{c}	215.6^{b}
	S	236.6^{a-e}	238.3^{a-d}	255.0^{a}	243.3^{a}	251.8^{a}	229.8^{b-g}	254.8^{a}	245.5^{a}	236.0^{a-e}	233.5^{a-f}	246.8^{ab}	238.8^{a}	242.5^{a}
Sedimentation index (cm^{3})	*C*	30.9^{ef}	29.3^{f}	35.8^{cd}	32.0^{b}	32.9^{ef}	26.9^{g}	36.3^{cd}	32.0^{b}	30.6^{ef}	27.1^{g}	34.9^{de}	30.9^{c}	31.6^{b}
	S	41.7^{c}	43.2^{b}	54.6^{a}	46.5^{a}	44.1^{b}	41.4^{c}	54.5^{a}	46.7^{a}	40.0^{c}	42.1^{bc}	53.8^{a}	45.3^{a}	46.2^{a}
Falling number – s	*C*	397.3^{a}	298.8^{b}	228.8^{d}	308.3^{b}	388.8^{a}	289.3^{b}	229.0^{d}	302.4^{b}	386.0^{a}	279.8^{cd}	218.5^{e}	294.8^{b}	301.8^{b}
	S	382.7^{a}	399.8^{a}	414.3^{a}	398.9^{a}	419.0^{a}	383.5^{a}	386.5^{a}	396.3^{a}	407.3^{a}	391.3^{a}	408.0^{a}	402.2^{a}	$399,1^{a}$

* *C* – common wheat, * *S* – spelt wheat,
a-j – values marked with the same letter do not differ significantly ($p < 0.05$)

the dough susceptible to mechanical processing (Sulewska et al. 2005, Schober et al. 2006). In our experiment, the quality of spelt wheat grain was improved by the value of the sedimentation index (providing direct information about the quality of gluten proteins), but on the other hand was diminished by the value of the falling number (indicative of the activity of alpha-amylase enzyme), which were higher by *ca* 50 and 30%, respectively, than in common wheat. Likewise, the lower starch content and the higher value of the falling number in spelt than in wheat were reported by Frakolaki et al. (2018).

A significantly higher content of protein was determined in the grain of both cereals grown after pea than after oilseed rape (by 8.6 and 4.9%, respectively) and after common wheat/spelt wheat (by 7.8 and 7.5%). Also Woźniak (2006) demonstrated a higher protein content in grain of wheat sown after pea than in grain of wheat from the successive culture. In all years of our experiment, the climate conditions promoted the growth of this forecrop, which resulted in its abundant post-harvest residues, rich in nitrogen, which were utilized by wheat. These residues are characterized by a narrow range of C:N values (low content of hemicelluloses and lignin, high content of nitrogen), which facilitates their rapid degradation and release of nitrogen, which successively is gradually absorbed by the main crop. Hence, the residues may increase both the yield and protein content of the main crop (Kaczmarska, Gawrońska-Kulesza 2000). No differences were found in the protein content between plots with common wheat grown after oilseed rape and plots with wheat succession, which is in agreement with results reported by Jaskulska et al. (2013) and Jankowski et al. (2015).

Grain of common wheat grown after itself contained less gluten compared to grain of common wheat cultivated after pea (by 7.4%), whereas spelt grain remained unaffected by forecrops in this respect. In addition, grain of common wheat had a lower value of Zeleny's sedimentation index than wheat grain after oilseed rape and pea (by 3.4%). These results are consistent with findings reported by Woźniak (2006), Jaskulska et al. (2013) and Jankowski et al. (2015), who demonstrated a decrease in the gluten content and sedimentation index value in grain of common wheat grown after itself. Tanács et al. (2010) are of the opinion that increased fertilization may improve the gluten content of the grain and its other quality traits, which may be in part true with regard to our results (richer residues of oilseed rape and pea compared to wheat residues – data not published). This is also confirmed by results reported by Babulicová and Gavurnikowá (2015), who demonstrated a higher gluten content of grain of common wheat grown after pea than after barley.

The content of starch and the falling number of grain of both studied cereals did not differ significantly as affected by the forecrop, which is consistent with results achieved by Piekarczyk (2010).

The effect of forecrops on changes in quality traits of the grain was negligible and differentiated also in particular study years.

Considering average values for years and forecrops, the grain of spelt wheat contained more Ca (by 12%) and Mn (by 16.8%), and less K (by 6.2%), Fe (by 9%) and Zn (by 9.2%) compared to common wheat grain (Table 4). The content of P, Mg and Cu was similar in grain of both cereals (insignificant differences). WAGA et al. (2002), who compared content of macroelements in grain of common wheat, spelt wheat and in hybrid cultivars, demonstrated that the hybrid cultivars (like cv. Rokosz analyzed in our experiment) had the same or even lower content of Mg, Fe and Zn than wheat. Also KRAWCZYK et al. (2008), who analyzed the ash content of grain, showed no significant differences between breeding lines of spelt wheat and common wheat. The forecrops had no effect on the content of P, K, Mg, Ca and Cu in the grain of both cereals. A higher content of Fe was determined in the grain of common wheat grown after oilseed rape than after pea and common wheat (by 16.3 and 15%, respectively), while a higher Zn content in grain of common wheat grown after pea (by 3.6% and 6.2% compared to the plots after oilseed rape and wheat, respectively). Spelt wheat cultivation after pea had a positive effect on Mn accumulation in its grain, the content of which was higher than in the grain of spelt wheat cultivated after oilseed rape and spelt wheat by 26.1 and 24.0%, respectively. A lower Fe content was demonstrated in the grain of spelt wheat grown after itself than in the grain of spelt wheat from plots after oilseed rape and pea (by 11.4 and 12.8%, respectively). Same as in our study, KRASKA et al. (2013) showed no effect of spelt wheat succession after itself on changes in the P content of its grain. In this cultivation system (spelt wheat after spelt wheat), the cited authors reported decreased content of Mg, Zn, Cu, Mn and Fe in the grain. According to WESOŁOWSKI and KWIATKOWSKI (2000), such a decrease results from multiple adverse changes proceeding in soil as a result of cultivating cereals after themselves (including wheat). In such an environment, cereals develop a weaker root system and are more severely invaded by stem base pathogens, which impairs the uptake of nutrients. However, in our study, this observation may only be related to the Fe content.

The interactions between the experimental factors demonstrated that in each study year the forecrops had no significant effect on the P content in the grain of both cereals and on content of K and Mg in common wheat grain. In the case of the other analyzed elements, the role of this experimental factor varied in different years.

The correlation analysis demonstrated positive correlations between grain yield of common wheat and the content of protein and gluten in this grain after all forecrops, between grain yield and falling number of the grain after pea and common wheat, and between grain yield and the Zn content in the grain harvested after pea (Table 5). In turn, a negative correlation was found between grain yield and the content of Ca, Cu and Fe in common wheat grain after all forecrops and between grain yield and the Mn content in common wheat grain harvested after pea. In the case of spelt wheat, significant correlations between grain yield and the analyzed traits were

Table 4

Content of some nutrients in grain of common wheat and spelt wheat

Element	Cereals	Forecrops												Mean
		oilseed rape				pea				wheat or spelt				
		years			mean	years			mean	years			mean	
		2013	2014	2015		2013	2014	2015		2013	2014	2015		
P (g kg-1)	*C**	2.6^{a}	2.5^{a}	2.3^{a}	2.5^{a}	2.9^{a}	2.8^{a}	2.9^{a}	2.9^{a}	2.7^{a}	2.4^{a}	2.7^{a}	2.6^{a}	2.7^{a}
	*S**	2.5^{a}	2.3^{a}	2.4^{a}	2.4^{a}	2.6^{a}	2.4^{a}	2.2^{a}	2.4^{a}	2.7^{a}	2.4^{a}	2.7^{a}	2.6^{a}	2.5^{a}
K (g kg-1)	*C*	4.6^{ab}	5.0^{a}	4.6^{ab}	4.7^{a}	4.6^{ab}	5.0^{a}	5.0^{a}	4.9^{a}	4.6^{ab}	5.0^{a}	4.6^{ab}	4.7^{a}	4.8^{a}
	S	4.3^{b}	4.3^{b}	4.6^{ab}	4.4^{b}	4.3^{b}	4.6^{a}	4.3^{b}	4.4^{b}	4.6^{a}	4.3^{b}	5.0^{a}	4.6^{b}	4.5^{b}
Mg (g kg-1)	*C*	1.0^{b}	1.0^{b}	1.0^{b}	1.0^{a}	1.0^{b}	1.0^{b}	1.0^{b}	1.0^{a}	1.0^{b}	1.0^{b}	1.0^{b}	1.0^{a}	1.0^{a}
	S	1.2^{a}	1.0^{b}	1.0^{b}	1.1^{a}	1.2^{a}	1.0^{b}	1.0^{b}	1.1^{a}	1.1^{b}	1.0^{b}	1.0^{b}	1.0^{a}	1.1^{a}
Ca (g·kg-1)	*C*	0.5^{c}	0.7^{a}	0.4^{d}	0.5^{b}	0.4^{d}	0.6^{b}	0.4^{d}	0.5^{b}	0.4^{d}	0.6^{b}	0.6^{b}	0.5^{b}	0.5^{b}
	S	0.7^{a}	0.6^{b}	0.6^{b}	0.6^{a}	0.7^{a}	0.4^{d}	0.6^{b}	0.6^{a}	0.7^{a}	0.6^{b}	0.4^{d}	0.6^{a}	0.6^{a}
Cu (mg kg-1)	*C*	1.8^{cd}	2.0^{c}	2.0^{c}	1.9^{a}	2.0^{c}	2.0^{c}	2.4^{ab}	2.1^{a}	2.0^{c}	2.4^{ab}	2.6^{a}	2.3^{a}	2.1^{a}
	S	2.0^{c}	2.4^{ab}	2.0^{c}	2.1^{a}	2.4^{ab}	2.2^{bc}	1.6^{d}	2.1^{a}	2.4^{ab}	2.4^{ab}	2.4^{ab}	2.4^{a}	2.2^{a}
Fe (mg kg-1)	*C*	86.2^{d}	99.9^{a}	87.8^{d}	91.3^{a}	69.8^{hi}	75.6^{fg}	90.0^{cd}	78.5^{b}	77.6^{ef}	80.0^{e}	80.6^{e}	79.4^{b}	83.1^{a}
	S	93.6^{bc}	66.6^{ij}	74.0^{fg}	78.1^{b}	96.6^{b}	65.6^{ij}	76.0^{ef}	79.4^{b}	65.2^{j}	71.4^{gh}	71.0^{h}	69.2^{c}	75.6^{b}
Zn (mg kg-1)	*C*	24.6^{bcd}	25.4^{abc}	24.8^{bcd}	24.9^{b}	26.8^{a}	25.4^{abc}	25.2^{bc}	25.8^{a}	24.8^{bcd}	25.2^{bc}	22.8^{efg}	24.3^{b}	25.0^{a}
	S	23.6^{def}	22.5^{fg}	22.6^{fg}	22.9^{c}	24.2^{cde}	20.8^{h}	22.4^{fg}	22.5^{c}	26.0^{ab}	21.4^{h}	20.6^{h}	22.7^{c}	22.7^{b}
Mn (mg kg-1)	*C*	25.4^{ghi}	29.2^{ef}	30.0^{cdef}	28.2^{c}	27.0^{gh}	29.4^{ef}	30.4^{def}	28.9^{bc}	25.8^{hi}	31.2^{c}	24.0^{i}	27.0^{c}	28.0^{b}
	S	26.2^{def}	31.6^{cd}	31.8^{cd}	29.9^{b}	38.0^{ab}	35.2^{b}	40.0^{a}	37.7^{a}	30.0^{def}	32.2^{cde}	29.0^{ef}	30.4^{b}	32.7^{a}

* *C* – common wheat, * *S* – spelt wheat

a-j – values marked with the same letter do not differ significantly ($p < 0.05$)

Table 5

Simple correlation coefficients for the relations between yield of grain of common wheat and spelt wheat and grain traits (n = 12)

Element	Common wheat			Spelt wheat		
	forecrops			forecrops		
	oilseed rape	pea	wheat	oilseed rape	pea	spelt
Protein	0.636*	0.882*	0.797*	-0.335	0.252	0.076
Gluten	0.587*	0.918*	0.825*	-0.457	0.316	-0.163
Starch	0.442	-0.159	-0.082	-0.812*	0.409	-0.368
Sedimentation index	0.471	0.249	0.252	-0.555	-0.250	-0.397
Falling number	0.295	0.829*	0.783*	-0.241	0.639*	0.185
P	0.412	0.378	0.412	-0.396	-0.189	0.294
K	-0.459	-0.791*	-0.459	-0.370	-0.446	-0.448
Mg	0.138	-0.083	0.138	-0.280	0.861*	0.448
Ca	-0.933*	-0.604*	-0.932*	-0.349	0.720*	0.711*
Cu	-0.767*	-0.582*	-0.767*	0.932*	0.600*	0.209
Fe	-0.657*	-0.634*	-0.657*	-0.613*	-0.910*	-0.963*
Zn	0.098	0.858*	0.098	-0.359	0.793*	0.978*
Mn	-0.489	-0.827*	-0.489	0.336	0.123	-0.202

* significant at $p < 0.05$

observed less often and were more diversified. A negative correlation was demonstrated between spelt wheat grain yield and the starch content in the grain from the plot after oilseed rape, and (as in the case of wheat) between grain yield and the Fe content in grain after all forecrops. In turn, positive correlations were found between grain yield and falling number and the Mg content – in grain from plot after pea, the Ca and Zn content – in grain from plots after pea and spelt wheat, and the Cu content – in grain from plots after oilseed rape and pea.

Different correlations were demonstrated between 1000 grain mass and the content of grain components (Table 6), as affected by the cereal, forecrop, and components. In the case of common wheat cultivated after oilseed rape, a significant positive correlation was found between grain mass and the Mn content in the grain, and a negative correlation between grain mass and the Cu content. When grown after pea, its grain mass was positively correlated with the content of protein, gluten, K and Mn in the grain, and negatively correlated with the falling number. In the case of spelt wheat, grain mass of the crop grown after oilseed rape was positively correlated with the content of protein, gluten, Cu and Mn, and negatively correlated with the content of Mg, Ca and Fe in the grain. In the crop cultivated after pea, grain mass was negatively correlated with the Ca content, and in that grown after spelt

Table 6

Simple correlation coefficients for the relations between the thousand grain weight of common wheat and spelt wheat and grain traits (n = 12)

Element	Common wheat			Spelt wheat		
	forecrops			forecrops		
	oilseed rape	pea	wheat	oilseed rape	pea	spelt
Protein	0.395	0.660*	0.427	0.767*	0.505	-0.259
Gluten	-0.706	0.614*	0.511	0.661*	0.263	0.374
Starch	0.95	0.123	-0.327	0.189	-0.100	0.069
Sedimentation index	0.254	-0.103	0.151	-0.428	0.287	0.309
Falling number	0.829	-0.631*	-0.426	0.125	-0.018	0.201
P	-0.569	0.214	0.468	-0.404	0.003	-0.322
K	0.348	0.677*	-0.277	0.128	-0.500	0.464
Mg	0.512	0.410	0.033	-0.667*	-0.254-	-0.318
Ca	0.164	0.289	0.205	-0.836*	-0.855*	-0.695*
Cu	-0.637*	0.290	0.093	0.602*	-542	-0.271
Fe	0.532	0.465	-0.126	-0.919*	-0.311	0.828*
Zn	0.179	-0.456	-0.466	-0.542	0.444	-0.867*
Mn	0.853*	0.723*	-0.309	0.880*	-0.747	0.132

* significant at $p < 0.05$

wheat it was positively correlated with the Fe content and negatively correlated with the Ca and Zn content.

The literature provides contradictory data on correlations between grain yield and content of elements in this grain. They demonstrate both decreased content of elements ('dilution effect'), small changes or increased content of elements along with the increasing grain yield (McGrath 1985, GaRvin et al. 2006, Yilmaz et al. 2017). These changes depend on many factors including the type of an element, genetic and physiological properties of cultivars, habitat conditions, agrotechnical measures, as well as the uptake on nutrients, their migration and accumulation in different parts of plant or their remobilization (Yilmaz et al. 2017). Based on longitudinal investigations, Fan et al. (2008) demonstrated a negative correlation between wheat grain yield and the content of Zn, Fe, Cu and Mg in this grain (R^2 = 0.56, R^2 = 0.33, R^2 = 0.45 and R^2 = 0.47, respectively). Significantly negative correlations between grain yield and the Zn and Fe content in the grain were also reported by Garvin et al. (2006). In contrast, McGrath (1985) showed no changes in the content of Fe, Zn, Cu, Mn and S in the grain along with a grain yield increase. Most of these changes were, however, positive, except for Mn, whose content did not increase along with the grain yield increase. In our study, there was no noticeable relation between 1000 grain mass and the content of the elements analyzed in this grain. Also Zhao et al. (2009) demonstrated a weak or insignificant correlation between grain size and grain content of elements. It may, therefore, be concluded that the content of elements in the grain depends on other than 1000 grain mass factors.

CONCLUSIONS

1. Grain yield of spelt wheat was by over 20% lower than that of common wheat. Spelt wheat grain contained more protein and wet gluten, and less starch. It was also richer in calcium and manganese, and poorer in potassium, iron and zinc compared to wheat grain.

2. The highest grain yield of both cereals was produced after winter oilseed rape. Their cultivation in the succession system significantly decreased the yield of grain. A stronger response to the succession system was observed in the case of spelt wheat.

3. Cultivation of common wheat and spelt wheat after pea had a positive effect on protein content in their grain, and also on gluten content in wheat grain. The forecrops had no effect on gluten content and Zeleny's sedimentation index in spelt wheat grain. In grain of common wheat grown after itself values of these parameters were lower than in grain of common wheat cultivated after pea and oilseed rape. The other technological parameters of grain of both cereals remained unaffected by the forecrops.

4. Forecrops did not affect the content of phosphorus, potassium, magnesium, calcium, and copper in grain of common wheat and spelt wheat. Grain of wheat contained more iron when grown after oilseed rape and more zinc when grown after pea, compared to the other forecrops. In turn, grain of spelt wheat had a higher manganese content when grown after pea and a lower iron content when grown after itself.

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