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SPELT WHEAT GRAIN YIELD AND NUTRITIONAL VALUE RESPONSE TO SOWING RATE AND NITROGEN FERTILIZATION

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ABSTRACT

Due to its valuable chemical composition, spelt enjoys huge interest among consumers and farmers. Research conducted in recent years has focused on winter varieties of this cereal, but there is a lack of information concerning the spring forms of spelt. In a three-year experiment yield and quality grain parameters of new spring breeding lines of spelt (A10 and A12) were evaluated depending on sowing rate (360, 480 and 600 grains m^{-2}) and nitrogen rate (50 and 80 kg ha^{-1}). Higher yield produced the spelt line A12, compared to A10. However, its grain contained less protein, gluten and fat as well as it showed lower contents of N, K, Mg, Zn and Mn. The different sowing rates did not have a significant effect on spelt yield and most of the grain quality parameters evaluated. Higher nitrogen application promoted lodging and caused a reduction in the number of ears per unit area. As a result, the grain yields were significantly lower compared to the rate of 50 kg N ha^{-1}. Under conditions of the higher nitrogen rate, a higher grain protein and gluten content as well as higher sedimentation index were found, while in turn spelt fertilized at the rate of 50 kg N ha^{-1} contained more starch and fat.

Key words: breeding lines of spring spelt, grain chemical composition, nitrogen rate, sowing rate, yield components

INTRODUCTION

Spelt wheat is an ancient crop plant known for thousand years. At the beginning of the 20th century, due to its low yield potential and the difficulties with grain dehulling, its crop area gradually declined in favor of more productive naked varieties of common wheat. In recent years, increased interest in this cereal has been observed in many countries. Spelt wheat contains many valuable nutrients necessary in human and animal diet (Kohajdová and Karovičova, 2008). Compared to common wheat, it contains more protein (Bonafaccia *et al.*, 2000), fat and vitamins as well as it is richer in minerals (Ruibal–Mendieta *et al.*, 2005; Stępień *et al.*, 2016).

Currently, the cultivation of spelt is concentrated in organic farms, but there are reports about its positive response to cropping intensification (Rachoń *et al.*, 2009; Andruszczak *et al.*, 2011). In recent years, many studies have been conducted on spelt wheat cultivation, but a large majority of them focused on winter cultivars of this cereal (Rachoń *et al.*, 2009; Podolska *et al.*, 2015; Biel *et al.*, 2016; Andruszczak, 2017). However, in the available literature there is a lack of studies concerning proper agronomy of the spring forms of spelt wheat and hence it is necessary to undertake research in this area. The literature data show that spelt cultivars differ in their requirements concerning mineral fertilizer rate and sowing density (Sulewska *et al.*, 2008a, b; Andruszczak *et al.*, 2011; Pospišil *et al.*, 2011). Therefore, the determination of agronomic requirements of new breeding lines is necessary from the point of view of science and agricultural practice. It also seems important to investigate how the above-mentioned factors affect the grain quality parameters.

The research hypothesis was that spelt grain yield and grain chemical composition are related to the genotype, but also to growing conditions modified by factors such as nitrogen fertilization and sowing rate. The aim of the present study was to evaluate the response of two new breeding lines of spring spelt wheat to different sowing rates and nitrogen rates.

MATERIALS AND METHODS

Experimental design: In 2012–2014, a field study was conducted at the Bezek Experimental Farm in the eastern part of Poland (51°19′ N, 23°25′ E). The experiment was established on medium heavy mixed rendzina soil derived from chalk rock, with the granulometric composition of loam. The soil had an alkaline reaction, high content of available P and K as well as a very low content of Mg. A three-factor experiment was set up as a split–split plot design in three replicates, with a harvested plot area of 15 m^2. Two breeding lines of the spring form of spelt wheat (*Triticum aestivum* ssp. *spelta* L.), i.e. A10 and A12, were the first-order factor. Sowing rate, which was 360, 480 and 600 grains m^{-2} (which corresponds to 150, 200 and 250 kg of spikelets per hectare), was the second-order factor. Nitrogen rate: 50 and 80 kg ha^{-1}, was the third experimental factor. The spelt breeding lines derive from University of Warmia and Mazury in Olsztyn.

Oat was the previous crop for spelt wheat. Sowing was carried out in the middle of April, while harvest in the middle of August. Before spring cultivation, the same mineral fertilization was applied in all experimental treatments at the following rates: N 50 kg ha^{-1} (ammonium nitrate), P 22 kg ha^{-1} (granulated triple superphosphate), and K 50 kg ha^{-1} (60% potassium salt). Additionally, 30 kg N ha^{-1} was applied at stem elongation in the treatments with the higher nitrogen rate.

Observations and measurements: At the heading stage (BBCH 55–59) LAI (leaf area index) and MTA (mean tip angle) were determined in the canopy of the spelt crop by performing nondestructive measurements using a LAI-2000 plant canopy analyzer (LI-COR, USA). It calculates the interception of blue light (320-490 nm) by the canopy at five zenith angles, simultaneously with a “fish eye” optical sensor. Measurements made above and below the canopy are used to determine the transmission of radiation by vegetation canopies. Four below-the-canopy measurements were repeated at three different locations in each plot. LAI and MTA are important variables that characterize vegetation canopy structure. Leaf area index is a ratio of the foliage area to the ground area, while mean tip angle refers to the description of the angular orientation of the leaves in the vegetation (leaves orientation in relation to the soil surface). Specifically, if the value of MTA is higher, plants have their leaves largely laying vertically (the leaves are more erect), while low MTA means that plants tend to maintain their leaves more horizontally. MTA has an impact on the reflectance, transmittance and absorption of solar light.

Evaluation of crop lodging was made at the dough stage of spelt wheat (BBCH 85) using a 9-point quality scale, where 9 means the best state, i.e. complete resistance, whereas 1 means the worst state, i.e. complete susceptibility to lodging. Before harvesting of spelt wheat, the height of plants and the length of ears were measured (based on 30 randomly chosen plants on each plot), and also the ear number on the area of 1 m^2 was calculated. Furthermore, ear length as well as number and weight of grains per ear were determined. After the grain was threshed in a LD 180 laboratory thresher (Wintersteiger, Austria), 1000 grain weight was determined. The grain yield obtained from each plot was converted into yield per hectare.

Assessment of grain quality: The quality traits of spelt grain were determined based on collective samples from each plot. The total protein, gluten and starch content in the grain, as well as Zeleny’s sedimentation index and moisture was determined with the use of Omeg Analizer G computer transmission analyzer of the whole grain (Bruins Instruments, Germany). Crude fat content was determined by Soxhlet method, total N by Kjeldahl method; P was determined using colorimetric assays with a vanadate-molybdate reagent; K and Ca – mineralization in sulfuric acid and oxygenated water, determination by flame photometry, photometer PEP7 (Jenway, UK); Mg – mineralization in sulfuric acid and oxygenated water, determination by atomic absorption spectrometry, spectrometer Perkin-Elmer (USA); Cu, Zn, Mn and Fe – mineralization in perchloric and nitric acid (1:4), determination by atomic absorption spectrometry, spectrometer Avanta (GBC Scientific Equipment, Australia), according to PN-EN 14084:2004. The chemical tests were carried out in an accredited laboratory (accreditation certificate No. AB 1375), issued by the Polish Centre for Accreditation. It meets requirements of the PN-EN ISO/IEC 17025:2005 standard.

Statistical analyses: Obtained results were elaborated statistically with the analysis of variance. Calculations were conducted with the use of statistical program ARStat, developed in the Faculty of Applied Mathematics and Information Technology of the University of Life Sciences in Lublin. The means were compared with the use of the least significant differences based on Tukey test ($P \leq 0.05$).

Weather conditions: In all years of the study, the average air temperature from April to August reached higher values (on average by 1.04 °C to 1.78 °C) than the long-term average for 1974–2010, but the greatest differences occurred in the first year of the study (Figure 1). At the same time, the year 2012 was characterized by the lowest total rainfall (255.4 mm), which was only 79% of the long-term mean (323.6 mm) (Figure 2). The years 2013 and 2014 were much wetter, since the total rainfall in these years exceeded the long-term average by 26% and 25%, respectively. Most rainfall was recorded in May 2014 as well as in May and June 2013 – the total rainfall in these months was higher than the long-term average by 164%, 98% and 86%, respectively. In turn, the highest water deficit occurred in July 2012 and 2014 as well as in August 2013.

RESULTS AND DISCUSSION

Grain yield and yield components: The results of the present study show no significant interactions between the experimental factors with respect to grain yield and chemical composition and therefore this paper presents the relationships of the traits studied with the main effects. The average grain yields of the spring breeding lines of spelt wheat (Table 1) were much lower than those for the winter cultivars investigated by Andruszczak *et al.* (2011) (4.07–4.45 t ha^{-1}), Lacko-Bartošová and Otepka (2001) (4.10–7.30 t ha^{-1}), and Stępień *et al.* (2016) (3.81–7.13 t ha^{-1}), but they were similar to those reported by Sulewska *et al.* (2008a) (2.57–2.73 t ha^{-1}). The spelt line

A12 produced significantly higher grain yields compared to the line A10, on average by 27%. Moreover, the line A12 was characterized by more horizontal leaf orientation in relation to the soil surface (as expressed by the lower value of the mean tip angle – MTA), lower plant height, greater resistance to lodging, and higher ear density. At the same time, ears of the spelt line A12 were longer than those of the line A10 and were characterized by a higher number and weight of grains.

Among the major components of cereal yields, ear density is commonly considered to be the factor that determines grain yield. The breeding lines of spelt wheat evaluated in this experiment were characterized by a relatively high ear density (535–588 pcs. m^{-2}), but they produced small grains with a low value of TGW. In a Czech study, the thousand grain weight of 15 landraces of spring spelt wheat was twice higher than in the present study, on average 42.59 g (Konvalina *et al*., 2010). On the other hand, the value of TGW for the winter forms of spelt wheat grown in Poland ranges 38.0–52.2 g (Andruszczak *et al*., 2011; Świeca *et al*., 2014; Podolska *et al*., 2015).

With an increase in sowing rate (from 360 up to 480 and 600 grains m^{-2}), there was an increasing trend in the leaf area index (LAI), ear density and grain yield, while the number of grains per ear decreased. However, the differences found were small and statistically insignificant. The absence of a significant response of spelt to sowing rate can probably be explained by the fact that the high sowing density resulted in an increase in the number of lateral tillers which often do not produce any yield but compete for assimilates with kernels in the main ear. A similar relationship is revealed in the study of Rüegger and Winzeler (1993) in which they demonstrated that an increase in spelt sowing density from 200 up to 400 grains m^{-2} contributed to an increase in ear density, but the grain yields were similar for both sowing rates. In the opinion of Sulewska *et al.* (2008a), spelt wheat is a cereal that has the characteristics of primitive species with strong crop self-regulation and that is why large changes in ear density are not always observed at different sowing rates. In the present study, the increase in grain yield depending on the sowing rate used was small, ranging from 4.3% to 5.2%. A similar effect (5.1%) was obtained by Troccoli and Codianni (2005) in using a sowing density of 100–200 seeds per $1m^2$. When sowing 500 seeds m^{-2}, Pużyński *et al.* (2015) showed a 8.5% increase in spelt grain yield in relation to a sowing density of 300 seeds m^{-2}, while in turn in experiments conducted in Croatia different sowing rates had no effect on the level of spelt yield (Pospišil *et al*., 2011).

The different nitrogen fertilization levels significantly affected plant height, lodging, ear density as well as LAI and MTA values, but had no impact on the other yield components. In evaluating spelt grain yield, it was found that the application of 50 kg N ha^{-1} was much more beneficial compared to the rate of 80 kg N ha^{-1}. In the opinion of Rajkumara (2008), the reason for lower cereal yields under intensive nitrogen fertilization is increased crop susceptibility to lodging, and yield losses can reach even 12–66%. This was confirmed in the present study which showed that the higher nitrogen rate significantly increased the height of spelt plants and promoted lodging. As a result, the grain yields dropped by 15.2% compared to the rate of 50 kg N ha^{-1}. Our previous study on winter spelt wheat cultivars demonstrated that mineral fertilization effectiveness was dependent on the genetic characteristics of the individual cultivars (Andruszczak *et al*., 2011). The application of higher NPK rates significantly increased the grain yield of the cultivar 'Schwabenkorn', but had no effect on the yield of cv. 'Spelt I.N.Z.'.

Lacko-Bartošová *et al.* (2010) emphasize the high variation in spelt yield depending on climatic conditions. This is confirmed by the studies of Stępień *et al.* (2016) as well as of Wojtkowiak and Stępień (2015) in which the difference in spelt grain yield between years with different weather conditions was about 87%. In the present experiment, the highest grain yields were obtained in the last year of the study in which the warm and wet weather, in particular during the period of intensive plant growth, promoted biomass production. The least favorable weather conditions occurred in 2012. The insufficient amount of rainfall observed in this year during the period between May and July, coupled with high air temperature, adversely affected the number of ears produced and grain size, while the yields obtained were lower by 17.7% and 25.7%, respectively, compared to 2013 and 2014.

The statistical analysis did not confirm a significant interaction of the experimental factors with grain yield. Nevertheless, it revealed a slightly different response of the evaluated spelt breeding lines to the cultivation treatments used (Figure 3). Under lower nitrogen fertilization conditions, with increasing sowing density the line A10 showed a decreasing trend in yield, while in the treatments with the rate of 80 kg N ha^{-1} the sowing rate of 480 grains m^{-2} proved to be most favorable. In the case of the line A12, the best effects were obtained in the treatment with 50 kg N ha^{-1} and the sowing rate of 480 grains m^{-2}.

Quality traits of grain: According to Buczek and Bobrecka-Jamro (2015), the genotype determines the response of a cultivar to external factors during the plant growth period, which in turn determines the specific value of the individual grain quality traits. In the present study, the line A10 showed a significantly higher grain protein, gluten and fat content in relation to A12 (Table 2). At the same time, it was characterized by higher

Zeleny sedimentation index, but contained significantly less starch.

Spelt wheat is considered to be a cereal with a high content of gluten-rich protein and this property has already been well documented (Escarnot *et al*., 2012). The contents of individual components in spelt grain reported by numerous authors vary, but they depend to a large extent and primarily on the genotype and habitat conditions. Zieliński *et al.* (2008) showed the grain protein content to range between 7.5% and 10.8%, while the gluten content between 30.1% and 37.2%. Bojňanská and Frančáková (2002) found 12.49%–19.48% of protein and 30.6%–51.8% of gluten, whereas in the study by Sulewska *et al*. (2005) these values were 13.3%–21.5% and 27.6–57.5%, respectively. Likewise, Escarnot *et al.* (2012) found high variation in the protein content of spelt grain, ranging from 9.8% to 25.5%. Starch content in spelt wheat also varies substantially. Bojňanská and Frančáková (2002) found the content of this component in spelt grain to range 48.3%–67.4%, while Zieliński *et al*. (2008) showed the starch content to be 71.6%–85.4%. These values are higher than those obtained in the present experiment (47.9–49.2%). Furthermore, the evaluated spring spelt lines were characterized by a lower fat content compared to the cultivars studied by Ruibal-Mendieta *et al*. (2005) (2.57–3.08 g 100 g^{-1}) as well as by Lacko-Bartošová and Otepka (2001) (2.53–3.04%).

Sowing rate resulted in significant differences in starch and fat content in spelt grain, but did not affect the other grain quality parameters. The opinions on the effect of sowing rate on nutrient content in spelt wheat grain are divergent. In the opinion of Biel *et al.* (2016), the chemical composition of spelt grain does not depend significantly on sowing density. Similar conclusions are also found in the paper by Pospišil *et al*. (2011). Podolska *et al.* (2015) obtained the most favorable parameters for spelt grain quality when they used a sowing rate of 500 seeds m^{-2} compared to the rates of 400 and 600 seeds m^{-2}, but significant differences were only found in case of the gluten content. Based on a study on winter spelt cultivars, Sulewska *et al*. (2008b) proved that under the influence of increasing sowing rate (from 200 up to 300 and 400 kg spikelets ha^{-1}) cv. 'Schwaberkorn' responded with an increase in grain protein content, while in cv. 'Bauländer', in turn, the protein content decreased. But the authors of this study did not show significant correlations between sowing density and fat content. In the present study, the largest amount of fat was found when the sowing rate of 360 grains m^{-2} was used, whereas the increase in sowing rate up to 480 and 600 grains m^{-2} significantly reduced the content of this component.

Increasing nitrogen rate caused a significant increase in protein and gluten content as well as in sedimentation value, but the grain starch and fat content decreased. Podolska *et al.* (2015) showed an increase in the protein content of spelt grain from 11.5% to 13.9% as affected by increased nitrogen rate up to 120 kg ha^{-1}, compared to the treatment without nitrogen fertilization, while Biel *et al*. (2010), in turn, obtained an increase from 133 to 179 g kg^{-1} DM using the same nitrogen rates.

Stępień *et al.* (2016) stress the significant impact of weather conditions on the grain quality parameters. In the present study, the highest amount of gluten in grain and the highest Zeleny sedimentation value were found in the hot and relatively dry growing season of 2012. In the second year of the study, spring spelt grain was characterized by the highest starch content, whereas the largest amount of protein and fat was found in the year 2014 which was characterized by higher air temperature and rainfall compared to the long-term means.

Macro- and micronutrients content: Spelt wheat is a rich source of macro- and micronutrients. Compared to common wheat, it contains on average from 30% to 60% more Fe, Zn, Cu, Mg and P (Ruibal-Mendieta *et al*., 2005). The spelt breeding lines evaluated in this experiment were characterized by a similar content of macro- and micronutrients as the eight winter spelt cultivars in the study by Kraska *et al.* (2013) (Table 3). On the other hand, Rachoń and Szumiło (2009) found in spelt grain more Mn (31.1–41.6 mg kg^{-1} DM.), Stępień *et al.* (2016) more Mn (32.6–35.09 mg kg^{-1} DM) and Fe (51.4–59.4 mg kg^{-1} DM), while Suchowilska *et al*. (2012) more Zn (47 mg kg^{-1}), Fe (50 mg kg^{-1}) and Cu (5.0 mg kg^{-1}). Ruibal-Mendieta *et al*. (2005), in turn, demonstrated a lower content of P (292.3 mg 100 g^{-1}), K (372 mg 100 g^{-1}), Zn (3.05 mg 100 g^{-1}) and Fe (3.11 mg 100 g^{-1}) in grain of two Belgian landraces, two experimental lines and five spelt cultivars compared to the results obtained in the present study.

In the opinion of Kraska *et al*. (2013), the content of individual elements in spelt grain is a trait that is strongly determined by the genetic factor (cultivar). This was confirmed in the present study which demonstrated that the spelt line A10, compared to A12, was characterized by a significantly higher content of N, K, Mg, Zn and Mn.

The different sowing rates determined the macro-and micronutrient content in spelt grain to a small extent and a statistically confirmed significant effect of this factor was only found in relation to Mn.

The higher nitrogen rate caused an increase in N and Zn content, but the grain content of the other elements decreased. However, compared to the treatment with the rate of 50 kg N ha^{-1}, the differences were small and statistically insignificant. Other relationships were found by Biel *et al.* (2010) who showed that with increasing nitrogen rate up to 40, 80 and 120 kg ha^{-1}, compared to the treatment without nitrogen fertilization, there was a significant increase in P and K content, whereas a decrease in Na. In their research concerning the effect of crop production intensity on grain chemical composition, Rachoń *et al*. (2015) demonstrated that at a nitrogen rate of 140 kg ha^{-1} spelt wheat contained more K, Ca, Mg and Cu, while at the same time less Mn than in the treatment with a rate of 70 kg N ha^{-1}. In turn, Stępień *et al.* (2016) showed a significant increase in Cu content and a decrease in P, Ca and Mn content under the influence of mineral fertilization at the following rates: N 90, P 30.2 and K 83.1 kg ha^{-1}, compared to the control (unfertilized) treatment.

The content of macro- and micronutrients (except for Mn) in spring spelt grain was significantly dependent on weather conditions during plant growth. Grain harvested in the first year of the study was characterized by the highest content of N, P, Mg and Ca. In turn, the lowest grain content of almost all elements studied (except for Mg and Cu) was found in 2013.

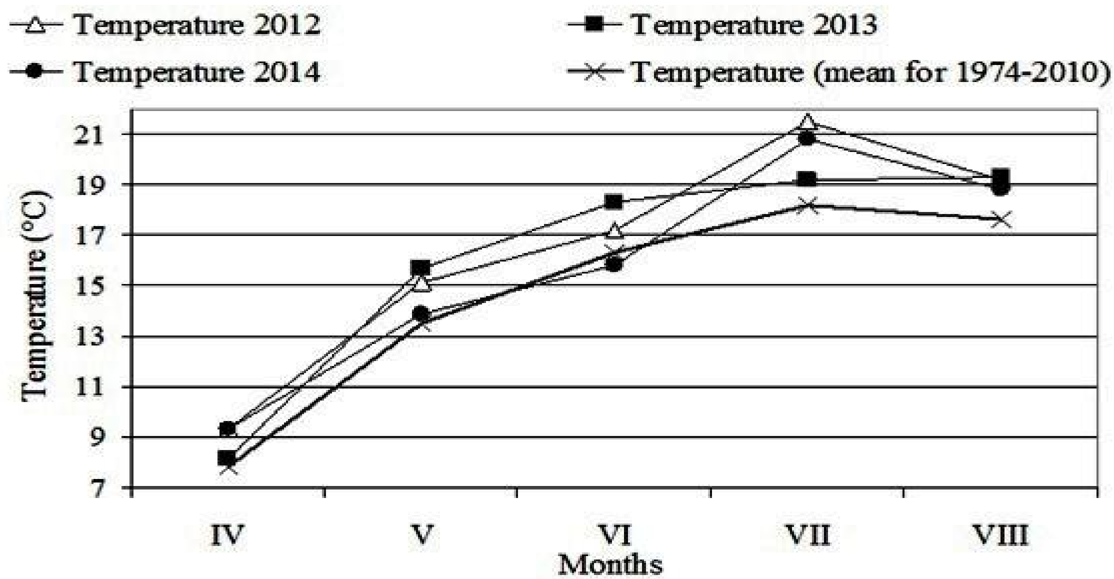

Figure 1. Air temperature in April-August in 2012–2014 as compared to the long-term means (1974–2010) according to the Meteorological Station at Bezek.

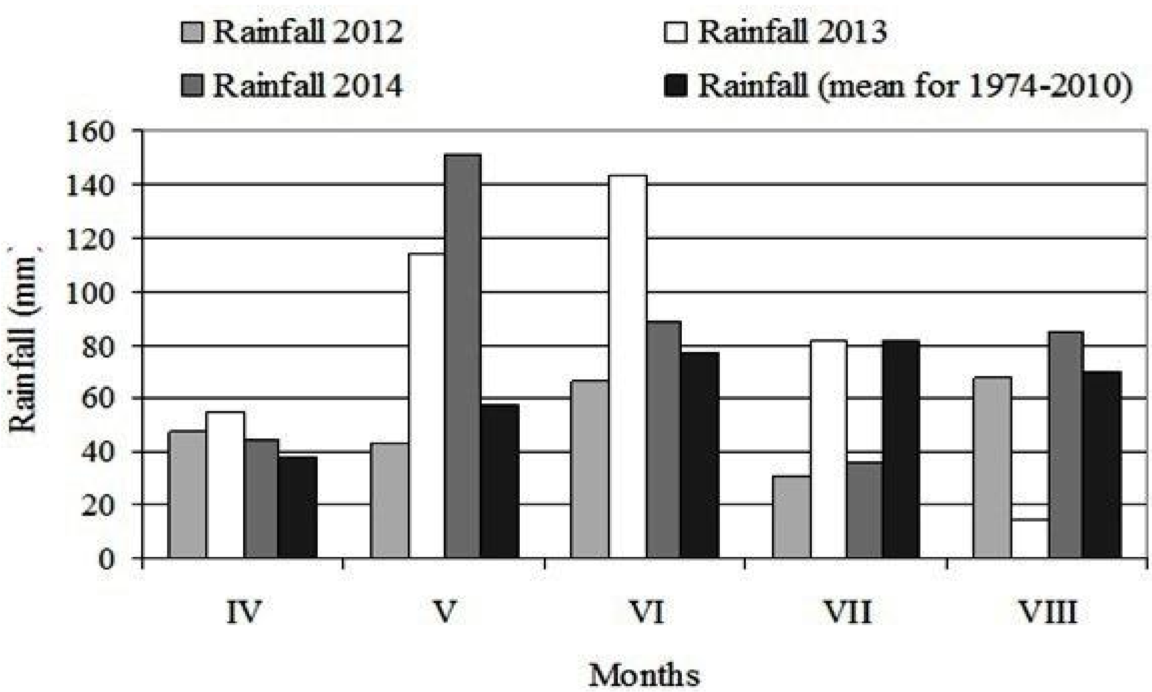

Figure 2. Rainfall in April-August in 2012–2014 as compared to the long-term means (1974–2010) according to the Meteorological Station at Bezek.

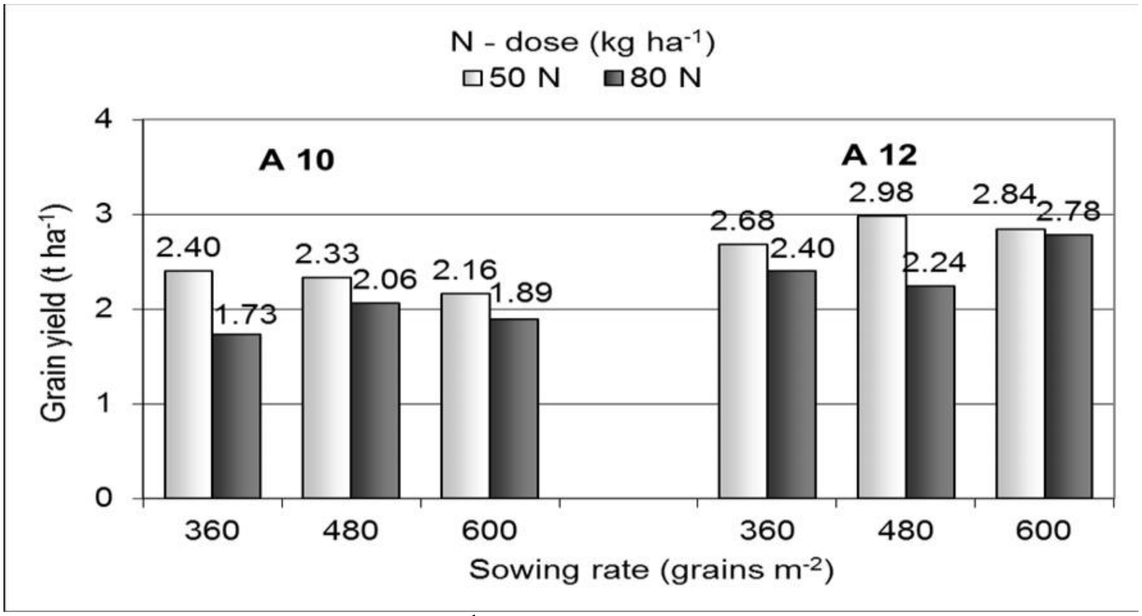

Figure 3. Grain yield of spring spelt wheat (t ha^{-1}) in different sowing rates, nitrogen doses and breeding lines (average for 2012–2014).

Table 1. The effect of breeding line, sowing rate and N-dose on some agronomic traits of spring spelt wheat.

Treatments	GY t ha^{-1}	LAI	MTA	PH cm	L 1–9	EN No. per 1 m^2	EL cm	NGE No. per ear	WGE g	WTG g
Breeding lines										
A10	2.09a	4.24a	44.8a	98.5a	5.1a	535a	9.8a	17.2a	0.39a	22.2a
A12	2.65b	4.12a	43.3b	95.4b	5.6b	588b	10.5b	21.5b	0.45b	21.4a
$LSD_{0.05}$	0.295	ns	1.34	1.87	0.23	47.5	0.30	1.43	0.031	ns
Sowing rate (grains m^{-2})										
360	2.30a	4.13a	44.1a	97.5a	5.3ab	530a	10.3a	19.8a	0.42a	21.8a
480	2.40a	4.20a	44.8a	96.7a	5.6a	564a	10.1a	19.6a	0.44a	22.4a
600	2.42a	4.21a	43.2a	96.7a	5.1b	590a	10.1a	18.7a	0.40a	21.2a
$LSD_{0.05}$	ns	ns	ns	ns	0.34	ns	ns	ns	ns	ns
N-dose (kg ha^{-1})										
50 N	2.57a	4.08a	44.8a	89.5a	6.0a	591a	10.2a	19.5a	0.43a	22.1a
80 N	2.18b	4.28b	43.3b	104.4b	4.6b	531b	10.1a	19.2a	0.41a	21.6a
$LSD_{0.05}$	0.295	0.142	1.34	1.87	0.23	47.5	ns	ns	ns	ns
Year										
2012	2.00a	4.59a	41.2a	96.4a	5.6a	524a	10.9a	22.6a	0.38a	14.9a
2013	2.43ab	3.91b	49.9b	97.4a	5.1b	573a	10.3b	18.0b	0.42ab	23.4b
2014	2.69b	4.03b	41.0a	97.2a	5.3ab	588a	9.3c	17.5b	0.46b	27.2c
$LSD_{0.05}$	0.434	0.209	1.97	ns	0.34	ns	0.44	2.10	0.046	1.98

Within columns, means followed by the same letter(s) are not significantly different at the $P \leq 0.05$; GY–grain yield; LAI–leaf area index; MTA–mean tip angle; PH–plant height; L–lodging; EN–ear number per 1 m^2; EL–ear length; NGE–number of grains per era; WGE–weight of grains per ear; WTG–weight of 1,000 grains; $LSD_{0.05}$–the least significant difference at the $P \leq 0.05$ level based on Tukey test; ns–non-significant

Table 2. The effect of breeding line, sowing rate and N-dose on some quality parameters of spring spelt wheat grain.

Treatments	Protein content (% DW)	Gluten content (%)	Starch content (%)	Zeleny's sedimentation index (ml)	Crude fat content (%)	Moisture (%)
Breeding line						
A10	18.1a	39.8a	47.9a	77.2a	1.95a	13.4a
A12	16.0b	32.5b	49.2b	63.0b	1.58b	13.6b
$LSD_{0.05}$	0.24	0.63	0.25	1.18	0.042	0.09
Sowing rate (grains m^{-2})						
360	17.0a	36.4a	48.4a	69.7a	1.83a	13.4a
480	17.0a	35.6a	48.8b	69.8a	1.74b	13.6a
600	17.0a	36.4a	48.5ab	70.9a	1.72b	13.5a
$LSD_{0.05}$	ns	ns	0.36	ns	0.066	ns
N-dose (kg ha^{-1})						
50 N	16.8a	35.4a	48.8a	68.9a	1.84a	13.5a
80 N	17.2b	36.8b	48.3b	71.3b	1.69b	13.5a
$LSD_{0.05}$	0.24	0.63	0.25	1.18	0.042	ns
Year						
2012	16.9a	40.1a	47.6a	75.1a	1.74a	13.0a
2013	16.3b	31.3b	50.5b	62.6b	1.74a	13.0a
2014	17.9c	37.0c	47.6a	72.6c	1.81b	14.4b
$LSD_{0.05}$	0.36	0.92	0.36	1.73	0.066	0.13

Within columns, means followed by the same letter(s) are not significantly different at the $P \leq 0.05$; $LSD_{0.05}$–the least significant difference at the $P \leq 0.05$ level based on Tukey test; ns–non-significant; DW–dry weight

Table 3. The effect of breeding line, sowing rate and N-dose on macro- (g kg^{-1} DM) and micronutrients (mg kg^{-1} DM) in grain of spring spelt wheat.

Treatments	N	P	K	Mg	Ca	Zn	Mn	Fe	Cu
Breeding line									
A10	30.1a	4.63a	4.34a	1.27a	0.23a	37.7a	26.4a	35.0a	3.54a
A12	25.8b	4.50a	4.22b	1.04b	0.23a	35.5b	24.0b	34.1a	3.59a
$LSD_{0.05}$	0.12	ns	0.082	0.094	ns	1.88	1.20	ns	ns
Sowing rate (grains m^{-2})									
360	28.4a	4.51a	4.23a	1.13a	0.22a	36.6a	26.9a	34.2a	3.66a
480	27.5a	4.60a	4.35a	1.20a	0.23a	35.2a	24.5b	33.8a	3.50a
600	27.9a	4.59a	4.25a	1.14a	0.24a	38.0a	24.2b	35.7a	3.55a
$LSD_{0.05}$	ns	ns	ns	ns	ns	ns	1.89	ns	ns
N-dose (kg ha^{-1})									
50 N	27.6a	4.61a	4.29a	1.17a	0.23a	35.9a	25.5a	34.8a	3.61a
80 N	28.4a	4.52a	4.26a	1.14a	0.23a	37.4a	24.9a	34.3a	3.52a
$LSD_{0.05}$	ns	ns	ns	ns	ns	ns	ns	ns	ns
Year									
2012	29.8a	4.82a	4.40a	1.03a	0.39a	39.9a	25.8a	28.7a	3.57ab
2013	24.5b	4.37b	3.88b	1.15ab	0.11b	30.2b	24.6a	28.3a	3.76a
2014	29.6c	4.51ab	4.55c	1.28b	0.19c	39.8a	25.4a	46.6b	3.37b
$LSD_{0.05}$	0.19	0.322	0.129	0.147	0.028	2.95	ns	3.77	0.223

Within columns, means followed by the same letter(s) are not significantly different at the $P \leq 0.05$; $LSD_{0.05}$–the least significant difference at the $P \leq 0.05$ level based on Tukey test; ns–non-significant

Conclusion: The present study and literature data show that spelt wheat contains many valuable nutrients. However, it is characterized by low yield potential, which limits its wide use in agricultural practice. The genetic characteristics were the factor that significantly determined spelt yield. Significantly higher grain yields (on average by 27%) were obtained in the case of the spelt line A12. Compared to the line A10, however, its grain was of slightly worse quality, as evidenced by the lower contents of protein, gluten and fat, the lower Zeleny sedimentation index as well as the lower contents of N, K, Mg, Zn and Mn.

The different sowing rates did not affect significantly spelt yield and most of the grain quality parameters evaluated. The higher nitrogen rate (80 kg ha^{-1}) promoted lodging and resulted in a reduction in the number of ears per unit area. As a result, compared to the rate of 50 kg N ha^{-1}, the grain yields were significantly lower (on average by 15%). Higher nitrogen fertilization had a beneficial effect on traits such as protein and gluten content or Zeleny sedimentation value, but the starch and fat content decreased. At the same time, the study did not show nitrogen rate to significantly affect macro- and micronutrient content.

The spring forms of spelt wheat evaluated in the present experiment were characterized by relatively low productivity, but taking into account their high quality, they may prove to be a valuable material for cultivation under organic farming conditions and in conventional low-input farms.

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