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Reaction of spelt wheat cultivars (*Triticum aestivum* ssp. *spelta*) to foliar applications of fertilizers

Reakcja odmian pszenicy orkisz (*Triticum aestivum spp. spelta*)
na dokarmianie dolistne

Summary. Field experiments were carried out in 2015–2017 on medium heavy mixed rendzina. The aim of the study was to assess the yield and weed infestation of winter spelt wheat cultivars (Oberkulmer Rotkorn, Badengold and Frankenkorn) under foliar application with Santaura Pro+ or Pro Horti Micro Amin Mg fertilizers.

Among the evaluated spelt cultivars, the largest yield of grain, as well as the largest number and weight of grains from ear was produced by Badengold cv., while the highest 1000-grains mass was characterized by Oberkulmer Rotkorn cv. Prohorti Micro Amin Mg foliar fertilizer was more yield-forming. Compared to the control object, three-fold application of this preparation resulted in a significant increase in the grain yield, the weight of 1000 grains, as well as number and weight of grains in the ear. Santaura Pro+ fertilizer also had a positive effect on the yielding of spelt, however differences in relation to the control object were statistically insignificant. Tested foliar fertilizers did not differentiate the weight of weed in the canopy of spelt.

Key words: grain yield, spelt wheat, foliar fertilizers, weed dry matter

INTRODUCTION

One of the oldest cereals used by humans is unthreshable spelt wheat (*Triticum aestivum* ssp. *spelta*) [Sulewska et al. 2008, Andruszczak et al. 2011]. In Poland, in the last dozen or so years, the popularity of spelt increased significantly, which is to a large extent related to the development of organic farming. Spelt wheat is considered a grain that works perfectly in this farming system [Kwiatkowski et al. 2014]. It does not require intensive fertilization and plant protection, and compared to common wheat, it is more resistant to diseases and environmental stresses [Andruszczak 2017a, 2017b, Kraska et al. 2019]. The presence of husk strictly adjacent to the kernel is a natural protection against pathogens, therefore spelt grain does not require seed dressing before sowing [Winzeler and Rüegger 1990]. In addition, it is more competitive against segetal flora [Feledyn-Szewczyk 2012].

Spelt grain contains many valuable nutrients necessary in the diet of humans and animals [Kraska et al. 2013, Świeca et al. 2014, Kwiatkowski et al. 2015, Rachoń et al. 2015]. According to some authors, it is characterized by more favorable chemical composition compared to the forms of common wheat [Stępień et al. 2016]. It contains components with antioxidant properties. In particular, these compounds include tocopherols, phenolic acids and phytosterols [Gawlik-Dziki et al. 2012]. Moreover, there is the possibility of culinary use of the so-called *green grain* harvested in the milk-wax ripeness stage [Kraska et al. 2019].

An important problem limiting the cultivation of spelt wheat is low yield potential. It is worth to pay attention to agrotechnical factors, the optimization of which would allow for a larger and stable grain yield. In the literature, there is little information on the impact of intensification of cultivation technology on the productivity of spelt wheat, therefore the research conducted in this field is still valid. Due to constantly growing interest in the cultivation of spelt wheat, it is important to study the reaction of different spelt genotypes to intensification of production. Valuable information is also the determination of competing abilities of spelt cultivars grown in Poland towards segetal flora.

The experiment assumed that direct supply of nutrients via foliar fertilization positively affect plant growth and increase spelt grain yield. The aim of the study was to compare the yield level and weed infestation of winter spelt wheat cultivars with the use of foliar fertilizers.

MATERIAL AND METHODS

A field experiment was carried out in 2015–2017 at the Bezek Experimental Farm located near the city of Chełm (51°19′ N, 23°25′ E), Poland. The experiment was established on a *Rendzic Phaeozem* [WRB 2006] originating from cretaceous bedrock, with the texture of loam – the textural class according to the Polish Society of Soil Science (2009). This soil is included in the bonitation class IIIb and the defective wheat complex. It was characterized by alkaline reaction (pH in 1 mol KCl – 7.35), high content of phosphorus (117.8 mg·kg^{-1} soil) and potassium (242.4 mg·kg^{-1} soil), while very low – magnesium (19.0 mg·kg^{-1} soil). The organic carbon content was 24.7 g·kg^{-1}.

Two-factor field experiment was established using the split-plot method in three replications with a plot area up to 12 m^2. The scheme of the experiment included three winter spelt wheat cultivars, i.e. Oberkulmer Rotkorn, Badengold and Frankenkorn. The second research factor was application of foliar fertilizers Santaura Pro+ or Pro Horti Micro Amin Mg fertilizers. Fertilizers were applied three times during the spelt vegetation, i.e. in the tillering stage (BBCH 23–25), stalk shooting (BBCH 33–35) and heading

(BBCH 53–55), in doses of 1 $l \cdot ha^{-1}$ and 4 $kg \cdot ha^{-1}$, respectively. The control object consisted of plots without foliar fertilizers. Santaura Pro+ is an organic fertilizer obtained from marine algae, containing nitrogen in the organic form (8%), potassium (K_2O 3%), microelements (iron, manganese, boron, zinc, copper), while the content of organic matter is 20%. Pro Horti Micro Amin Mg fertilizer includes: total nitrogen (2.0%), ammonium nitrogen (2%), magnesium oxide (20.0%), sulfur trioxide (39.3%), boron (0.05%), water soluble molybdenum (0.01%), amino acid (5.0%), zinc chelated by IDHA (0.1%), copper chelated by IDHA (0.05%), iron chelated by IDHA (0.15%) and manganese chelated by IDHA (0.2%).

Soil cultivation was carried out in accordance with generally accepted agrotechnical recommendations for winter wheat. After harvesting the previous crop (oats), plowing and harrowing were made. The sowing plowing plus harrowing was made about 3 weeks before sowing the spelt. Harrowing was also performed immediately before spelt sowing. Spelt wheat spikelets were sown at the beginning of October in the amount of 350 kg per hectare. Mineral fertilization was as follows (in kg of pure ingredient per hectare): N 60 (20 + 40); P 26.2; K 83. Phosphate fertilizers in the form of triple granulated superphosphate and potassium fertilizer in the form of 60% potassium salt as well as 20 kg $N \cdot ha^{-1}$ in the form of ammonium nitrate, were sown before spelt sowing. In spring, 40 kg $N \cdot ha^{-1}$ were carried in the stalk shooting phase (BBCH 32–34). In the tillering phase of spelt (BBCH 24–29), herbicides Aminopielik Tercet 500 SL (2,4-D in the amount of 300 g per 1 liter of the product, mecoprop in the amount of 160 g per 1 liter of the product, dikamba in the amount of 40 g per 1 liter of the product) and Puma Universal 069 EW (fenoxaprop-P-ethyl in the amount of 69 g per 1 liter of the product) at doses of 2.5 $l \cdot ha^{-1}$ and 1.0 $l \cdot ha^{-1}$, respectively, were applied.

Evaluation of the weed infestation level was carried out by the botanical-weight method during the spelt tillering. An air-dry mass of weeds was determined, taking their aboveground part from four randomly selected sites of each plot, marked with a frame of 1 m × 0.25 m. Before the harvest of spelt wheat, the height of 30 randomly selected plants in the field was measured on each plot, while production shoots were counted on sample surfaces of 1 m^2, determined in two replications with a frame of 0.5 m^2. In addition, the number and weight of grains per 1 ear and the weight of 1000 kernels were determined on 30 ears harvested from each plot. After harvesting with the use of combine harvester, the obtained spelt spikelets from each plot (12 m^2) were threshed in the Wintersteiger LD 180 threshing machine and the grain yield per hectare was determined.

The obtained results were statistically analyzed by analysis of variance. The means were compared using least significant differences based on the Tukey's test ($P \leq 0.05$). Calculations were made using the ARSTAT statistical program, developed at the Faculty of Applied Mathematics and Information Technology of the University of Life Sciences in Lublin.

RESULTS AND DISCUSSION

Under conditions of the research, the ear density of spelt cultivars assessed was at a similar level (Table 1). There were also no significant differences depending on the foliar fertilizers used. However, under the influence of Santaura Pro+ and Prohorti Micro

Amin Mg products, there was a tendency of a greater number of spelt ears, by 1.7% and 2.1% respectively, compared to the control object. Similarly, Jablonskytė-Raščė et. al. [2013], by applying the foliar fertilization with Terra Sorb Foliar, obtained an increase in the density of spelt wheat plants. In turn, Szumiło et al. [2019] reported an increase in the number of spelt ears due to the foliar application of Kelpak SL.

Table 1. Effect of cultivar and foliar application of fertilizers on the ear density of spelt wheat (pcs.·m^{-2}) (average for 2015–2017)

Cultivars	Foliar fertilizers			Mean
	Control	Santaura Pro+	Prohorti Micro Amin Mg	
Oberkulmer Rotkorn	509	521	529	519
Badengold	516	527	530	524
Frankenkorn	520	524	520	521
Mean	515	524	526	–
$LSD_{0.05}$	Cultivars (A) n.s. Foliar fertilizers (B) n.s. (A) × (B) n.s.			

n.s. – dependency not statistically significant

The evaluated foliar fertilizers did not have any significant impact on the height of spelt wheat plants, while significant differences between cultivars were demonstrated (Table 2). Irrespective of foliar feeding, the highest height in the field was achieved by Oberkulmer Rotkorn, while the remaining cultivars were significantly lower, by 14–17 cm on average). In studies by Andruszczak [2017a] conducted on the same soil, the height of spelt plants was much lower (Oberkulmer Rotkorn – 120 cm, Badengold – 106 cm, and Frankenkorn – 108 cm); however, it should be noted that the growth regulator was used in these studies.

Table 2. Effect of cultivar and foliar application of fertilizers on the height of spelt wheat (cm) (average for 2015–2017)

Cultivars	Foliar fertilizers			Mean
	Control	Santaura Pro+	Prohorti Micro Amin Mg	
Oberkulmer Rotkorn	133	136	138	135
Badengold	118	118	119	118
Frankenkorn	119	122	122	121
Mean	123	125	126	–
$LSD_{0.05}$	Cultivars (A) 4.6 Foliar fertilizers (B) n.s. (A) × (B) n.s.			

n.s. – dependency not statistically significant

Badengold cultivar was characterized by significantly higher number and weight of grains per ear compared to Oberkulmer Rotkorn and Frankenkorn (Table 3, Table 4). Similarly, in the studies of Andruszczak [2017a], values of these features determined for

Badengold cv. were higher in comparison to seven evaluated cultivars of spelt wheat. The triple application of Prohorti Micro Amin Mg, regardless of the spelt cultivar, resulted in a significant increase in the number and weight of grains per ear in relation to the control object. A beneficial effect on the investigated spelt characteristics was also found for the Santaura Pro+ fertilizer (increase in the number and weight of grains in the ear by 4.5% and 5.0%, respectively compared to the control), but statistical verification did not confirm the significance of these differences. A proven interaction between the experimental factors showed that Frankenkorn cv. fertilized with Prohorti Micro Amin Mg produced larger number and mass of grains in ears than in the control plots. These results coincide with those by Zain et al. [2015], which showed that foliar fertilization with micronutrients ($FeSO_4$ + $ZnSO_4$ + $MnSO_4$) improves the fertility of the ears. At the same time, the highest number of grains in the wheat ear was obtained after the application of $ZnSO_4$ + $MnSO_4$.

Table 3. Effect of cultivar and foliar application of fertilizers on the number of grains per ear of spelt wheat (average for 2015–2017)

Cultivars	Foliar fertilizers			Mean
	Control	Santaura Pro+	Prohorti Micro Amin Mg	
Oberkulmer Rotkorn	23.7	23.5	23.7	23.7
Badengold	28.2	29.7	30.3	29.4
Frankenkorn	22.2	24.2	26.1	24.1
Mean	24.7	25.8	26.7	–
$LSD_{0.05}$	Cultivars (A) 1.28 Foliar fertilizers (B) 1.57 (A) × (B) 3.24			

Table 4. Effect of cultivar and foliar application of fertilizers on the grain weight per ear of spelt wheat (g) (average for 2015–2017)

Cultivars	Foliar fertilizers			Mean
	Control	Santaura Pro+	Prohorti Micro Amin Mg	
Oberkulmer Rotkorn	1.01	1.01	1.01	1.01
Badengold	1.12	1.17	1.19	1.16
Frankenkorn	0.86	0.96	1.06	0.96
Mean	1.00	1.05	1.08	–
$LSD_{0.05}$	Cultivars (A) 0.067 Foliar fertilizers (B) 0.074 (A) × (B) 0.128			

The largest mass of 1000 grains was determined for the cultivar of spelt wheat Oberkulmer Rotkorn. Regardless of the foliar fertilization, value of this feature was higher compared to other cultivars by 3.9% and 7.3% on average; however, statistically confirmed differences were found only in relation to the Frankenkorn cv. (Table 5).

Application of Prohorti Micro Amin Mg foliar fertilizer, regardless of the spelt cultivar, resulted in a significantly higher mass of 1000 grains (Table 5). Statistical analysis of the obtained results, however, indicates different reaction of the examined cultivars of spelt to the applied foliar fertilizers. Significant differentiation of this feature under the influence of applied fertilizers was found only for Frankenkorn cv. Value of 1000-grain mass for this cultivar in the object with Prohorti Micro Amin Mg fertilizer was significantly higher than in the variant with Santaura Pro+ and in the control without foliar application of fertilizers (Table 5). In the research conducted so far on the optimization of spelt wheat fertilization, different trends in the spelt reaction to the applied macro- and microelements were noticed. Andruszczak et al. [2011] found that the intensification of mineral fertilization significantly increased the spike density and grain yield, but it had no influence on the number and weight of grains per ear and 1000-grain weight. Stępień et al. [2017] showed that NPK fertilization and general mineral fertilization supplemented with microelements (Cu, Zn, Mn) had little effect on the number and weight of grains from the spelt wheat ear. An exception was the weight of 1000 grains, which increased under the influence of additional fertilization of plants with copper. Similarly, Amin et al. [2016] indicate that the use of foliar zinc sulphate increases the weight of 1000-grains. Pospišil et al. [2016] dividing the nitrogen dose in the spelt wheat canopy of the Ostro cv., obtained clearly larger 1000-grain mass (50.4 g) than in the present study. Szumiło et al. [2019] have shown that spraying the canopy with an algal extract had beneficial effect on density of spelt spikelet, as well as the number and weight of spelt grains per spikelet. However, this treatment did not increase the weight of 1000 grains. Also Jablonskytė-Raščė et. al. [2013], using foliar fertilization, obtained an increase in the number and weight of grains in spelt wheat ears.

Table 5. Effect of cultivar and foliar application of fertilizers on the 1000-grain mass of spelt wheat (g) (average for 2015–2017)

Cultivars	Foliar fertilizers			Mean
	Control	Santaura Pro+	Prohorti Micro Amin Mg	
Oberkulmer Rotkorn	42.8	42.4	41.9	42.4
Badengold	40.4	40.4	41.5	40.8
Frankenkorn	38.2	38.9	41.4	39.5
Mean	40.5	40.6	41.6	–
$LSD_{0,05}$	Cultivars (A) 1,91 Foliar fertilizers (B) 1.05 (A) × (B) 2.00			

The largest yield of spelt grain was recorded in objects with Badengold cv. Regardless of foliar fertilization, it was significantly larger by 16.2% compared to the variant with Oberkulmer Rotkorn and by 22.1% than obtained for the Frankenkorn cultivar (Table 6). It is worth paying attention to the fact that weed infestation measured with the air dry weight of weeds was the largest on plots with Badengold cv. (Table 7). However, in general, it was low and had no decisive influence on grain yield. In the study by Andruszczak [2017a], like in the discussed experiment, the Badengold cultivar also had the highest yield among the spelt genotypes assessed.

Foliar application of fertilizers had a beneficial effect on spelt yielding. Regardless of the cultivar, grain yield increased compared to the control object on average from 6.1% to 11.0%, with significant differences only in the variant with Prohorti Micro Amin Mg. The best yield effect of the applied foliar fertilizers was found for Frankenkorn cv. Under the influence of Santaura Pro+ and Prohorti Micro Amin Mg fertilizers, this cultivar yielded higher than in the control object by 9.7% and 22.5%, respectively. Similarly, for the Badengold cv., these differences amounted to 7.0% and 8.4%, and for the Oberkulmer Rotkorn cv. – 2.1% and 3.9% (Table 6). This confirms the opinion of Andruszczak et al. [2011], that selection of appropriate cultivars is essential for the size of the spelt grain yield.

Table 6. Effect of cultivar and foliar application of fertilizers on grain yield of spelt wheat ($t \cdot ha^{-2}$) (average for 2015–2017)

Cultivars	Foliar fertilizers			Mean
	Control	Santaura Pro+	Prohorti Micro Amin Mg	
Oberkulmer Rotkorn	5.08	5.19	5.28	5.18
Badengold	5.72	6.12	6.20	6.02
Frankenkorn	4.45	4.88	5.45	4.93
Mean	5.08	5.39	5.64	–
$LSD_{0,05}$	Cultivars (A) 0.404 Foliar fertilizers (B) 0.394 (A) × (B) n.s.			

n.s. – dependency not statistically significant

In the studies of Stępień et al. [2016], combined use of general mineral fertilization (NPK) with an organic growth stimulator – NANO-GRO® – had no effect on grain yield and the majority of crop structure characteristics tested. In other studies, Wojtkowiak and Stępień [2015] and Stępień and Wojtkowiak [2016] obtained a marked increase in the yield of spelt wheat and common wheat after foliar application of 1% solution of $ZnSO_4$, $CuSO_4$ and 0.5% $MnSO_4$ solution. The foliar application of 0.2 $kg \cdot ha^{-1}$ Cu, Zn and Mn and the complex of these elements together with NPK fertilization also had a beneficial effect on spelt grain yield [Stępień et al. 2017]. Jablonskytė-Raščė et al. [2013] as well as Wojtkowiak and Stępień (2015) obtained similar results. This confirms the thesis presented by Knapowski et al. [2016] and Andruszczak [2017a], that spelt wheat reacts by increasing the grain yield in conditions of intensification of production technology.

Table 7. Effect of cultivar and foliar application of fertilizers on the dry matter of weeds in canopy of spelt wheat ($g \cdot m^{-2}$) (average for 2015–2017)

Cultivars	Foliar fertilizers			Mean
	Control	Santaura Pro+	Prohorti Micro Amin Mg	
Oberkulmer Rotkorn	16.6	14.2	12.8	14.6
Badengold	24.0	34.4	32.7	30.4
Frankenkorn	17.1	20.0	17.9	18.3
Mean	19.2	22.9	21.1	–
$LSD_{0,05}$	Cultivars (A) 6.32 Foliar feeding of plants (B) n.s. (A) × (B) n.s.			

n.s. – dependency not statistically significant

Wróbel [2009], using boron (H_3BO_3) in the form of foliar application in the canopy of barley and oats, obtained significant increase in grain yield in comparison with other methods of this element application and with a control object without boron fertilization. Also Aciksoz et al. [2011], using foliar application of Fe in the canopy of durum wheat, obtained an increase in grain yield. Habib [2010] using 150 g·ha^{-1} Zn ($ZnSO_4$) or Fe (Fe_2O_3) and combinations of these two microelements, obtained an increase in wheat yield, compared to the object without foliar fertilizers, respectively by 3.3%, 6.8% and 16.8%. Khan et al. [2009], using 5 kg·ha^{-1} Zn ($ZnSO_4$), found an increase in wheat grain yield by 31.6% compared to the control. Zain et al. [2015] obtained similar increase in wheat grain yield using foliar application of $FeSO_4$ + $ZnSO_4$ + $MnSO_4$ or $FeSO_4$ + $MnSO_4$. In turn, Korzeniowska and Stanisławska-Glubiak [2011] obtained a 20% increase in the yield of winter wheat as a result of the foliar application of copper.

The applied foliar fertilizers did not significantly differentiate the weight of weeds in the canopy of spelt (Table 7). In research by Andruszczak et al. [2012a], higher level of mineral fertilization slightly increased the number of weeds in the spelt plot; however, it did not affect their air-dry mass and number of species. In the canopy of Badengold cultivar, regardless of foliar fertilization, significantly higher dry weight of weeds compared to the other cultivars, was found. Badengold cv. was also characterized by the lowest height (Table 2), which probably determined its competitiveness in relation to weeds. This clearly indicates the differential pressure of spelt cultivars to the development of segetal flora in the field, and at the same time creating real opportunities to select the most competitive cultivars for a specific position. Obtained results are concurrent with the research conducted by Feledyn-Szewczyk [2013], which indicate that the proper selection of cultivated wheat cultivars has a large impact on the level of weed infestation in terms of their ability to compete with weeds. The diversified competitiveness of wheat cultivars with weeds is to a large extent related to the height and leaf surface, especially in the initial stages of their development [Drews et al. 2009; Feledyn-Szewczyk 2012]. Andruszczak et al. [2012b], referring to Badengold cv., determined the smallest LAI in the milk-dough stage (BBCH 77-88) compared to the cultivars of Oberkulmer Rotkorn and Frankenkorn. On the other hand, in the stage of shooting and tillering, the LAI indicator for Badengold cv. was close to that of Oberkulmer Rotkorn cv. and clearly smaller than for Frankenkorn cv.

CONCLUSIONS

1. The selection of cultivars was the most important factor in the yielding of spelt. Irrespective of the foliar fertilization of plants, Badengold cv. yielded the best, whereas cultivars of Oberkulmer Rotkorn and Frankenkorn produced significantly lower grain yields, respectively by 14.0% and 18.1%.

2. The largest number and weight of grains from the ear was produced by Badengold cv., while the highest plant height and weight of 1000-grains was characterized by the Oberkulmer Rotkorn cv. Compared cultivars of spelt did not differ significantly in terms of spike density.

3. Foliar application of fertilizers positively influenced the yield of grain and elements of the yield structure of spelt wheat. Regardless of the cultivar, a better yield effect was obtained after the application of Prohorti Micro Amin Mg. In comparison to the control object, the use of this fertilizer significantly increased the value of 1000-grain mass and the number and mass of grains in the ear, while grain yield increased by an average of 11.0%.

4. Spelt wheat produced larger yield of grain under the influence of Santaura Pro+ fertilizer; however, the differences obtained in relation to the control object were statistically insignificant.

5. Selection of the cultivar had a decisive influence on the level of weed infestation of spelt wheat. In objects, where cultivars Oberkulmer Rotkorn and Frankenkorn were sown, the smaller air-dry mass of weeds was determined than in the canopy of Badengold cv., which was probably determined by height of plants. However, due to the right selection of herbicides, the level of weed infestation was low and did not have much impact on the yield of spelt wheat grain.

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Streszczenie. Badania polowe przeprowadzono w latach 2015–2017 na średnio ciężkiej rędzinie mieszanej. Celem pracy była ocena plonowania i zachwaszczenia ozimych odmian pszenicy orkisz (Oberkulmer Rotkorn, Badengold i Frankenkorn) w warunkach stosowania dokarmiania dolistnego nawozami Santaura Pro+ lub Pro Horti Micro Amin Mg.

Spośród ocenianych odmian orkiszu największy plon ziarna, a także największą liczbę i masę ziaren z kłosa wytworzyła odmiana Badengold, natomiast największą masą 1000 ziaren odznaczała się odmiana Oberkulmer Rotkorn. Bardziej plonotwórczy był nawóz dolistny Prohorti Micro Amin Mg. W porównaniu z obiektem kontrolnym trzykrotna aplikacja tego preparatu skutkowała istotnym zwiększeniem plonu ziarna, masy 1000 ziaren, a także liczby i masy ziaren w kłosie. Nawóz Santaura Pro+ także wpłynął korzystnie na plonowanie orkiszu, jednak uzyskane różnice w odniesieniu do obiektu kontrolnego były statystycznie nieistotne. Stosowane nawozy dolistne nie miały wpływu na zachwaszczenie łanu.

Słowa kluczowe: plon ziarna, orkisz, dolistne dokarmianie, sucha masa chwastów

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