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Impact of sowing depth and seed size on the dynamics of germination and productivity of spring wheat

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Abstract. In the years of 2013–2014, pot experiments were conducted to determine the influence of sowing depth and seed size on the dynamics of spring wheat emergence and yields. The study was carried out in Mitscherlich pots using the random block method, in four replications. The experiment included spring wheat cultivar Tybalt. The first factor of the experiment was the sowing depth of seeds (1, 3, 5, 7 cm), while the second factor was the seed yield. Four levels of the second factor were taken into account: a1 – certified material (purchased), a2 – small-sized seeds (1.8 – 2.2 mm), a3 – medium seeds (2.2 – 2.5 mm), a4 – large seeds (> 2.5 mm). Adequate size of seeds for the study was ensured by sorting out of the certified material on Vogel screens. The research showed the joint impact of seed size and sowing depth on grain yield formation, number of plants and ears per pot and production tillering. The application of the sowing depth of 7 cm resulted in a significant decrease in grain yield from the pot of all seed fractions, especially the smallest fraction of seeds (1.8 – 2.2 mm). The variant of sowing large seeds (> 2.5 mm) at the depth of 3 cm turned out to be the most beneficial for grain yield.

Keywords: spring wheat, seed size, sowing depth, germination rate, grain yield, yield components

INTRODUCTION

The depth of seed sowing is one of the key factors influencing the level of crop yield. It depends on the type and properties of the seeds, sowing date and soil type (mechanical structure and variable factors – humidity, temperature and degree of soil aeration). As far as yields are concerned, it is remarkably important to retain a constant sowing depth as well as to thoroughly cover the seeds. Even plant germination is a guarantee of the same growth and development of all plants (Markowski et al., 2013). Seed is one of the fundamental factors affecting yielding of cereal plants. Its quality is determined by the degree of certification, germination capacity, purity, health and plumpness of the seeds. The plumpness is determined on the basis of the grain weight or its size (Kwiatkowski, 2004). Former studies indicate that the grain size significantly affects the dynamics and germination index as well as the grain yield (Jaskulski, 2003; Podolska, Sułek, 2002; Sułek, 2007).

Little research has been conducted on the impact of the sowing depth and seed quality on the germination dynamics and cereal yielding. Thus, model studies were carried out to determine the effects of the sowing depth and seed size on the germination dynamics, yield and the components of spring wheat yielding.

MATERIALS AND METHODS

The experiments were conducted in 2013 and 2014 in the vegetation hall of the Institute of Soil Science and Plant Cultivation – State Research Institute in Puławy. The research was carried out in Mitscherlich pots using the randomised block method in four replications. The Tybalt spring wheat variety was employed for the tests. The first factor of the experiment was the sowing depth (1, 3, 5, 7 cm), while the second was the grain size. Four levels of the second factor were taken into account: a1 – unsorted certified material, a2 – small seeds (1.8–2.2 mm), a3 – medium seeds (2.2–2.5 mm), a4 – large seeds (> 2.5 mm). The appropriate size of the seeds for the study was ensured by sorting the certified material using Vogel sieves. The characteristics of the seeds are summarised in Table 1.

Seed sowing was performed on the 16.04.2013 and 30.03.2014. The pots were filled with pseudo-podzolic soil mixed with Vistula sand in a ratio of 5:2, weighing 7 kg. Nitrogen was administered in the form of NH_4NO_3, in the

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Table 1. Characteristics of spring wheat seeds used for sowing.

Years	Share of seed fraction in certified material [%]			1000 grain weight [%]			
	small (1.8–2.2)	medium (2.2–2.5 mm)	large (>2.5 mm)	certified	small (1.8–2.2)	medium (2.2–2.5 mm)	large (>2.5 mm)
2013	4.4	13.9	81.7	42.0	20.9	34.3	49.7
2014	4.7	15.6	79.7	41.5	18.9	29.8	47.3

amount of 2.4 g N/pot, using ½ a dose before sowing and ½ a dose during the stem shooting phase (BBCH – 36). Prior to sowing, fertilisation with the remaining components per pot included: P_2O_5 – 1 g in the form of KH_2PO_4, K_2O – 1.5 g in the form of K_2SO_4, Mg – 0.6 g in the form of $MgSO_4 .7H_2O$. Moreover, iron (50 mg), boron (5 mg) and copper (3 mg) were added to the soil. Ten grains were sown into each pot. The soil humidity was maintained at a level of 60% of the field water capacity throughout the entire growing season.

During the experiments, the dynamics of germination was determined at each treatment by daily counting of the germinated plants from the day of the first germination to the end of this phase. Harvest was done at full maturity (BBCH – 84). The number of plants and ears, productive propagation, grain weight from the plant and from the ear, number of grains from the plant and from the ear as well as the grain weight from the pot and the weight of 1000 grains were determined. The results of the research were statistically analysed by the Statistica v. 10.1 package using the ANOVA method of analysis of variance. The differences were estimated with the Tukey's test at a significance level of p=0.05.

The results of the studies concerning the grain yield and its components are given in the tables as averages for the years, while the dynamics of germination is presented in the figures for particular years.

RESULTS AND DISCUSSION

The statistical analysis revealed a significant interaction of particular factors of the experiment and the years affected observed germination dynamics. The size of grains and their sowing depth differentiated the dynamics of spring wheat germination (Fig. 1–8). In 2013, the seeds were sown on 16.04, and the emergence of plants under the sowing conditions to a depth of 1 cm was observed after 6 days (22. 04). On that day, the unsorted certified seeds sprouted the most (33%), while the large seeds sprouted the least (26.6%). Considerably less sprouting was recorded for medium (17%) and small (10%) seeds. After 9 days, when germination was completed, the germination percentage for certified seeds was 98%, for medium and large seeds 97%, and for small seeds 88% (Fig. 1). After sowing wheat seeds to a depth of 3 cm (Fig. 2), the beginning of germination was reported after 7 days. The most seeds germinated in the treatment with unsorted certified seeds (48%). 37% of large seeds and 38% of small seeds germinated, whereas the lowest germination index was found in the treatment with medium seeds (32%). Seed germination of all fractions was completed after 8 days. 100% of unsorted certified seeds, 98% of large seeds and 97% of medium seeds germinated. The lowest germination index was recorded in the treatment with small seeds (85%). When the seeds were sown to a depth of 5 cm, the beginning of germination was noticed after 9 days (25.04). On that day, the highest percentage of germination (53%) was noticed in the treatments with medium seeds, and then unsorted certified seeds (40%). 38% of large seeds ger-

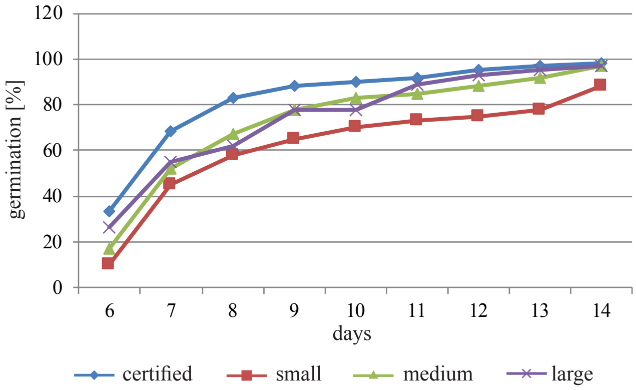

Figure 1. Dynamics and percentage of emergence of spring wheat when sowing seeds to a depth of 1 cm in 2013.

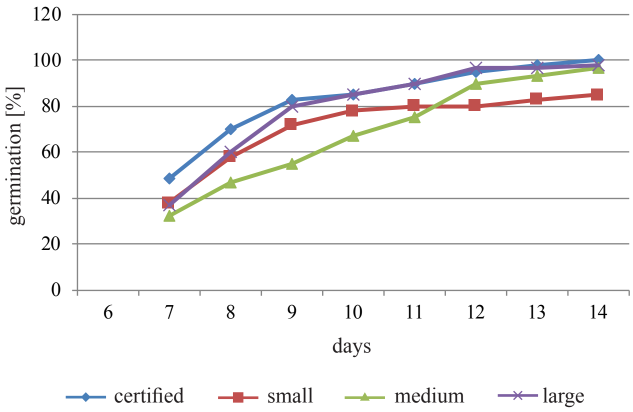

Figure 2. Dynamics and percentage of emergence of spring wheat when sowing seeds to a depth of 3 cm in 2013.

minated, and the lowest germination was recorded in the treatment with small seeds (12%). The seed germination of all fractions lasted 6 days, and the highest seed germination index was recorded in the treatment with medium (95%) and large (90%) seeds. 88% of unsorted certified seeds germinated. A smaller percentage of germination was recorded in the treatment with small seeds (52%) (Fig. 3). Under the conditions of sowing wheat seeds to a depth of 7 cm, the beginning of germination was recorded after 9 days. The highest percentage of germination was recorded after sowing unsorted certified seeds (23%), while the lowest percentage was noted after sowing small seeds (5%). The germination of unsorted and fractionated seeds lasted 6 days. Large seeds germinated at the highest rate (85%). Less germination was observed in the treatment with unsorted (65%) and medium (60%) seeds, while the lowest germination index was found in the treatment with small seeds (36%) (Fig. 4). The results of the study indicate that in 2013, the beginning of wheat germination was evidently delayed by the depth of seed sowing, whereas the time to reach full germination capacity was shortened (Fig. 1–4).

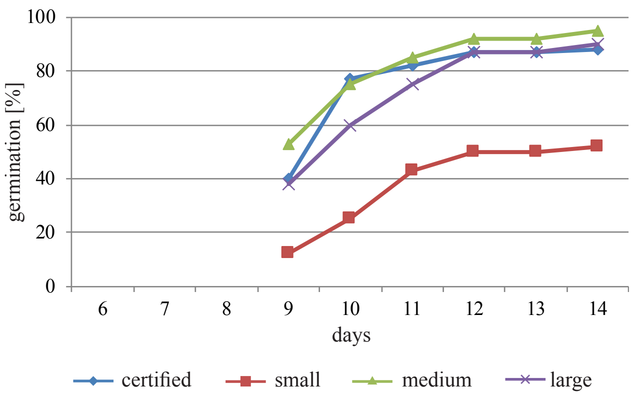

Figure 3. Dynamics and percentage of emergence of spring wheat when sowing seeds to a depth of 5 cm in 2013.

In 2014, sowing was performed on 30.03, and the beginning of germination was recorded 8 days after sowing. On that day, after sowing the seeds to a depth of 1 cm, large seeds and unsorted certified seeds germinated the most. The respective germination percentages were 83% and 73%. A lower percentage of germination was determined in treatments with small and medium seeds, i.e. 35% and 58%, respectively. After 6 days, when the germination of unsorted seeds was completed, the germination percentage reached 100%. The germination of small and large seeds was completed after 9 days and also reached 100%. The germination of medium seeds took 1 day longer and ended at 100% (Fig. 5). After sowing the wheat seeds to a depth of 3 cm, the unsorted, large and medium seeds germinated after 8 days. In this case, large seeds germinated the most (39%), followed by medium seeds (25%) and unsorted seeds (10%). It was noted that small seeds began germinating a day later; however, the percentage of germination was the same as in the case of medium seeds (25%). The germination of medium and small seeds was the fastest and took 6 days. The percentage of germination reached 100% and 96%, respectively. The germination of unsorted certified seeds lasted 1 day longer and reached 98%. The germination of large seeds took the longest, i.e. 8 days, and reached 100% (Fig. 6). In the case of sowing wheat seeds at a depth of 5 cm, the fastest germination, i.e. 9 days, was determined for unsorted certified seeds and medium seeds (12% and 6%, respectively). The germination of large and small seeds began after 11 days and the germination percentage was 19% and 22%, respectively. The longest germination of 10 days was noted in treatments with unsorted certified seeds and large seeds. The germination in this case reached 90% and 92%, respectively. The germination of small seeds took the shortest amount of time, i.e. 5 days. After this time, 79% of small seeds germinated (Fig. 7). When the wheat seeds were sown to a depth of 7 cm, germination began after 11 days. At this time, 29% of certified unsorted seeds, 19% of medium seeds and 12% of large

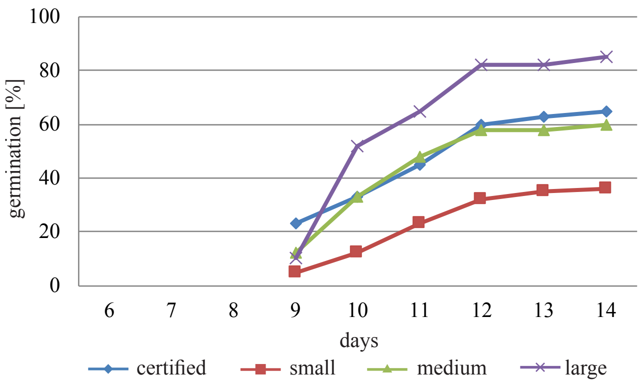

Figure 4. Dynamics and percentage of emergence of spring wheat when sowing seeds to a depth of 7 cm in 2013.

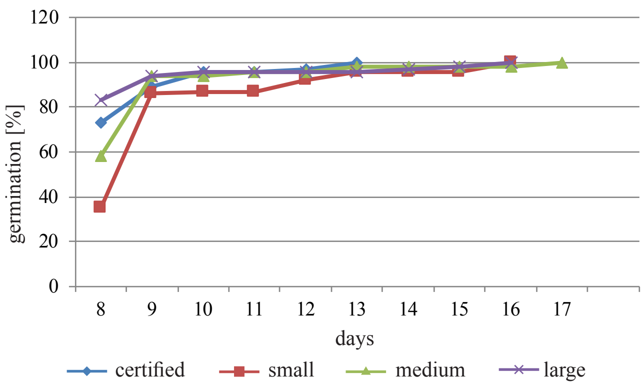

Figure 5. Dynamics and percentage of emergence of spring wheat when sowing seeds to a depth of 1 cm in 2014.

seeds germinated (Fig. 8). The germination in the treatment with small seeds was noted a day later. In this case, 8% of small seeds germinated. The germination of large seeds lasted 8 days and reached 64%. Germination took 6 days in treatments with unsorted and small seeds. The germination percentage for unsorted seeds was 71%, while for small seeds 54% (Fig. 8).

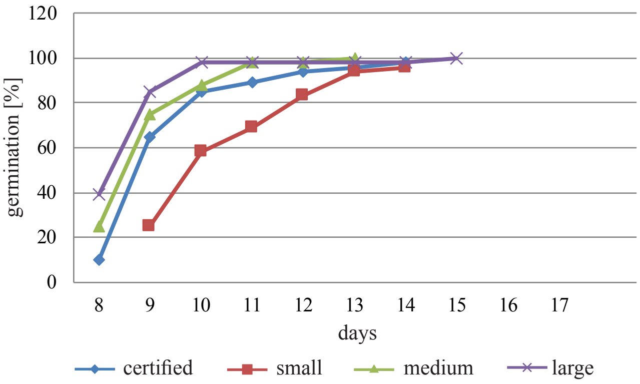

Figure 6. Dynamics and percentage of emergence of spring wheat when sowing seeds to a depth of 3 cm in 2014.

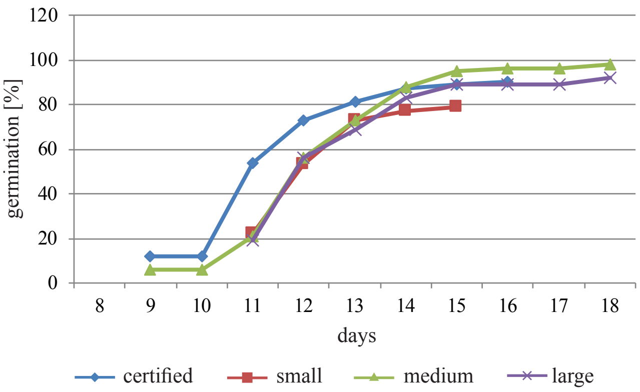

Figure 7. Dynamics and percentage of emergence of spring wheat when sowing seeds to a depth of 5 cm in 2014.

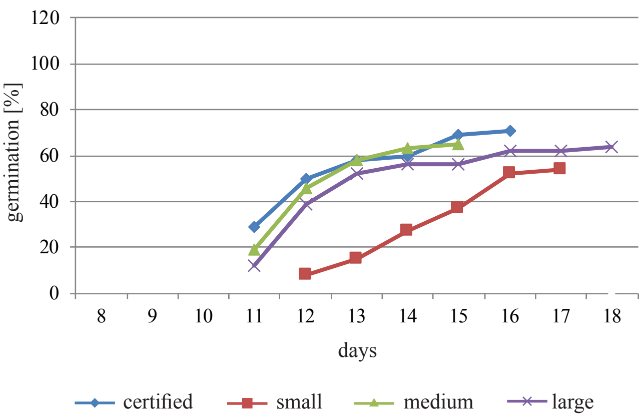

Figure 8. Dynamics and percentage of emergence of spring wheat when sowing seeds to a depth of 7 cm in 2014.

The presented results have been partially confirmed by other studies (Sułek, 2007; Podolska, 2008; Jaskulski, 2003; Tavakoli Kakhki et al., 2008), which indicate that large grain is characterised by faster and fuller germination. Other authors (Kirby, 1993; Yagmur, Kaydan, 2009) emphasise that the plant germination depends on the depth of sowing and that placing the seed too deep into the soil results in poorer germination.

The statistical analysis showed a lack of interaction between years and experimental factors. Thus, the results of the study concerning the yield and elements of its structure are presented as averages for 2013 and 2014 (Tables 2–4). Based on the analysis of variance, significant differentiation of the grain yield from the pot as a result of the sowing depth and seed size was found and the interaction between these factors was demonstrated.

This study unequivocally revealed that sowing seeds with a diameter of more than 2.5 mm and unsorted certified seeds, which contained approximately 80% of fractions >2.5 mm (Table 1), led to significantly higher grain yields compared to those in the treatments with small seeds (Table 2). Notably, these outcomes are consistent with the results previously reported by other authors. Podlaski et al. (1993) claim that the separation of small grains from the seed increases the yield of winter wheat and spring barley by 8.5% and 7.1%, respectively. Earlier studies by Sułek (2007) demonstrated that the highest yield of spring wheat grain was obtained from certified material, which was 30.6%, 18.6% and 4.7% higher than those obtained from small, medium and large seeds, correspondingly. In this study, the highest yield of the seed from a pot was obtained by sowing large seeds. The yield exceeded those obtained by sowing medium seeds, unsorted seeds and small seeds by 4.2%, 8.8% and 12%, respectively. These results are confirmed by the study conducted by Wasilewski et al. (2014), who indicated that by sowing spring wheat with a seed fraction above 2.8 mm, the grain yield was higher than the yield obtained from seeds with a fraction of 2.2–2.5 mm by 7.9%. The beneficial effects of sowing the largest fraction of seeds on the grain yield of winter wheat and winter triticale was also demonstrated by Sułek and Podolska (2004), Parylak and Wojtala (2008) and Wojtala-Łozowska and Parylak (2010).

The depth of sowing seeds had a significant impact on the yield of spring wheat (Table 2). The highest yield of the grain from a pot was obtained after sowing wheat to a depth of 3 cm. The yield was 5.5% and 25.1% higher than those achieved after sowing seeds to a depth of 5 and 7 cm, respectively. The research conducted by Yagmur and Kaydan (2009) also showed a significant effect of the sowing depth on wheat yielding. The authors proved that wheat sown at a depth of 5 cm gave a 19.9%, 22.3% and 62.5% higher grain yield than that sown at 2, 7 and 9 cm, correspondingly. In a study concerning spelt wheat, Sulewska (2004) stated that spikelets deep sowing at 6 cm resulted in a higher yield. However, this relationship was not observed when sowing grains.

Our own research indicates that sowing of the examined seed fractions at a depth of 1 and 3 cm did not cause differences in the yielding of spring wheat. Conversely, placing the seeds at a depth of 5 and 7 cm led to differences in the grain yield between the seed fractions (Table 3). After sowing large seeds (>2.5 mm) to a depth of 5 and 7 cm, wheat yielded a respectively 21,3% and 22,6% higher grain yield from a pot than that obtained from small seeds. Statistical analysis revealed a significant variation in the number of plants and ears from a pot depending on the sowing depth and seed size. Moreover, there was an interaction between the studied factors, which influenced these features (Tables 2–4).

The research results showed a significantly smaller number of plants and ears from a pot after sowing small seeds (Table 2). Studies conducted by Wasilewski et al. (2014) revealed that the number of plants after germination did not depend on the size of the seeds. Moreover, the number of ears per unit area was considerably higher when sowing seeds of the fraction above 2.8 mm.

The sowing depth had a significant effect on the number of plants and ears from a pot. The lowest number of plants and ears from a pot was obtained after sowing seeds to a depth of 7 cm (Table 2). Yagmur and Kaydan (2009) showed that the sowing depth of wheat seeds also differentiated the number of plants and ears per unit area. In their study, the highest number of plants per unit area was obtained after sowing seeds to a depth of 7 cm, whereas the highest number of ears was noted at a sowing depth of 5 cm. Deep sowing above 7 cm resulted in a considerable reduction in the number of plants and ears per unit area. Furthermore, in her research on spelt wheat, Sulewska (2004) stated that the ear density per unit area depended on the depth of sowing seeds and was higher at 6 cm than at 2 cm.

When sowing seeds to a depth of 1 and 3 cm, no significant differences were found in the number of plants and ears from a pot between the tested seed fractions (Table 4). However, placing the seeds at a depth of 7 cm resulted in a significant reduction in the number of plants and ears in treatments with small and medium seeds.

A statistically significant impact of the sowing depth and seed size was found. In addition, an interaction between the factors that shape the tillering of spring wheat plants was determined (Tables 2 and 3). The research indicated that the spring wheat plants exhibited the highest tillering after sowing small seeds (Table 2). When conducting microplot experiments with spring wheat and spring triticale, other authors (Sułek, 2007; Nieróbca, Podolska,

Table 2. Impact of seed size and sowing depth on spring wheat yield and yield components (averaged over experiment years.

Traits	Seed size [mm]				Sowing depth [cm]			
	certified	small (1.8–2.2)	medium (2.2–2.5)	large (>2.5)	1	3	5	7
Grain yield [g per pot]	59.5 c	57.4 d	62.5 b	65.2 a	63.4 b	67.4 a	63.7 b	50.5 c
Plant number per pot	9.0 a	7.6 b	8.8 a	9.1 a	9.9 a	9.8 a	8.5 b	6.3 c
Head number per pot	29.2 a	27.0 b	27.4 b	29.2 a	31.2 a	31.3 a	28.2 a	22.0 b
Tillering	3.3 ab	3.7 a	3.1 b	3.2 b	3.2 b	3.2 b	3.3 a	3.6 a
1000 grain weight [g]	40.7 b	41.4 b	42.8 a	42.2 a	40.6 b	41.3 ab	42.3 a	42.2 a
Grain weight per plant [g]	6.69 b	7.78 a	7.21 a	7.30 a	6.41 b	6.81 c	7.52 b	8.19 a
Grain number per plant	164.3 b	188.3 b	167.4 ab	171.8 a	157.2 b	165.7 a	178.1 ab	190.8 ab
Yield per ear [g]	1.48 a	1.78 a	1.67 a	1.58 a	1.41 b	1.52 b	1.70 a	1.88 a
Grain number per ear	50.4 a	51.6 a	53.4 a	53.2 a	49.7 b	51.9 ab	53.5 a	53.7 a

Different letters denote statistically significant differences (α = 0.05)

Table 3. Impact of sowing depth and seed size on grain yield and production tillering per pot of spring wheat (averaged over experiment years).

Traits	Grain yield [g per pot]				Tillering			
	sowing depth [cm]							
	1	3	5	7	1	3	5	7
Certified	59.1 a	65.6 a	63.1 ab	50.0 ab	3.2 a	3.2 a	3.3 ba	3.3 b
Small (1.8–2.2 mm)	64.2 a	66.4 a	55.2 b	43.6 b	3.3 a	3.4 a	3.8 a	4.2 a
Medium (2.2–2.5 mm)	67.3 a	64.4 a	66.5 ab	52.0 ab	3.0 a	3.1 a	3.1 b	3.3 b
Large (> 2.5 mm)	63.0 a	72.9 a	70.1 a	56.3 a	3.2 a	3.1 a	3.2 b	3.5 b

Different letters denote statistically significant differences (α = 0.05)

Table 4. Impact of sowing depth on the number of plants and ears per pot of spring wheat (averaged over experiment years

Traits	Plant number per pot				Head number per pot			
	sowing depth [cm]							
	1	3	5	7	1	3	5	7
Certified	10.0 a	10.0 a	8.8 a	7.8 a	32.0 a	32.3 a	29.5 a	22.8 ab
Small (1.8–2.2 mm)	9.5 a	9.3 a	7.0 b	7.7 a	31.2 a	31.8 a	25.7 b	19.3 b
Medium (2.2–2.5 mm)	10.0 a	9.8 a	9.3 a	6.2 b	29.8 a	30.2 a	29.0 a	20.5 ab
Large (> 2.5 mm)	10.0 a	10.0 a	9.0 a	7.3 a	32.0 a	31.0 a	28.5 a	25.2 a

Different letters denote statistically significant differences ($\alpha = 0.05$)

2006) proved that plants grown from large seeds achieved better tillering than those grown from small seeds.

The sowing depth affected the tillering of spring wheat. The highest value was obtained after sowing wheat seeds to a depth of 5 and 7 cm (Table 2). Moreover, the interaction between the studied factors and plant tillering was confirmed. When sowing the seeds to a depth of 1 and 3 cm, no significant differences were noted in the plant tillering between the seed fractions. In contrast, when sowing seeds to a depth of 5 and 7 cm, considerably greater plant tillering was noted in treatments with small seeds (Table 3).

The results of the research indicate that the grain plumpness specified by the weight of 1000 grains was significantly dependent on the sowing depth and size of the seeds. There was no evidence of a significant interaction between the factors and their effect on the weight of 1000 grains. Important differences in the TGW were found between the seed fractions used for sowing. Grains obtained from treatments, in which large and medium seeds were sown, were characterised by significantly greater TGW (Table 2). According to other studies (Sułek, 2007; Podolska, 2008), the seed size does not affect the obtained weight of 1000 grains of spring and winter wheat. The grains acquired from treatments, in which the wheat was sown to a depth of 1 cm, were characterised by the lowest weight of 1000 grains. The weight was approximately 4% lower than the TGW's obtained by sowing seeds at a depth of 5 and 7 cm (Table 2).

Statistical analysis revealed that the grain weight and the number of grains per plant were also affected by the sowing depth and size of the seeds. However, the weight and number of grains per ear was affected only by the sowing depth (Table 2). There was no evidence of any interactions between factors with regard to these features. The lowest weight of grain from a plant was found in treatments with certified unsorted seeds. Moreover, the weight of grain from a plant did not differ significantly between the remaining seed fractions. Podolska's (2008) research on winter wheat indicated that the size of the sown grains did not affect the amount of the grain from the plant and ear or the number of grains from the plant. Conversely, in studies on spring wheat, other authors (Sułek, 2007; Wasilewski et al., 2014) obtained significantly lower grain weight and number of grains from an ear after sowing seeds from the smallest fraction. The seed sowing depth differentiated the weight of the seed from the plant and ear as well as the number of grains from the ear (Table 2). A higher weight of grain from a plant was obtained after sowing seeds at a depth of 7 cm than at 1, 3 and 5 cm. The highest weight of grain and number of grains from an ear, however, were found in treatments with seeds sown at a depth of 5 and 7 cm. In the studies conducted by Sulewska et al. (2004), a higher grain weight from an ear was obtained after sowing at a depth of 6 cm than at a depth of 2 cm. In addition, shallow sowing increased the number of grains from an ear. The research carried out by Yagmur and Kaydan (2009) also indicated that sowing wheat at a depth of 7 cm increased the grain weight from an ear.

SUMMARY

1. The dynamics and percentage of germination depended on the seed size and depth of sowing. A higher percentage of germination was noted after sowing seeds with the largest fraction (>2.5 mm). Deeper wheat sowing at 5 and 7 cm resulted in a delay in germination and a smaller number of germinated seeds, particularly those with the smallest fraction (1.8–2.2 mm).
2. The size of the sown grains affected the grain yield from a pot and the yield components. The highest grain yield was obtained after sowing large seeds, and the lowest after sowing small seeds.
3. The sowing depth determined the spring wheat yield. Specifically, placing seeds at a depth of 7 cm significantly reduced the grain yield.
4. The influence of seed size and sowing depth on the grain yield, number of plants and ears from a pot as well as productive tillering was confirmed. Sowing seeds at a depth of 7 cm resulted in a significant reduction in the grain yield from a pot of all seed fractions, particularly the smallest fraction (1.8–2.2 mm).
5. The variant of sowing large seeds (>2.5 mm) to a depth of 3 cm turned out to be the most favourable for grain yield.

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