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The yield of selected cultivars of spring barley depending on the sowing rate

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Abstract. The aim of the study was to determine the response of new cultivars of spring barley in terms of the grain yield, yield components and protein content in grains, to an increase in the sowing rate. Microplot experiments were carried out in the IUNG-PIB experimental plot in Puławy, where the influence of the following sowing densities on the yielding of selected cultivars was studied: 250, 350 and 450 grains m^{-2}. In the years 2011–2012, the following cultivars were investigated: Basic, Goodluck, Iron, KWS Olof, Natasia, and in the years 2012–2013 cultivars: Despina, Ella, Fariba, Gawrosz (hulless variety), Kucyk and Raskud. The experiments were carried out on a soil of a good wheat complex (heavy loamy sand deposited on light loam). An increase in grain yield (averaged across cultivars) was obtained as the sowing density was increased up to 450 grains m^{-2}. At a high sowing rate (450 grains m^{-2}), a significant increase in the grain yield of the following cultivars occurred: Basic, Iron, Despina and Gawrosz, and an increase in the yielding of other cultivars at this sowing rate, compared to the sowing rate of 350 grains m^{-2}, constituted a trend. The largest increases in the yield at a high sowing rate, in comparison to the low rate in the first series of experiments (2011–2012), were demonstrated by the following varieties: Iron (29%), Basic (25%) and Goodluck (21%), and smaller increases were noted for the cultivars: KWS Olof (13%) and Natasia (10%). In the second series (2012–2013), higher yields at a high sowing rate, as opposed to a low sowing rate, were demonstrated by the following cultivars: Gawrosz, Raskud and Despina (31–34%), and lower yields by: Ella, Fariba and Kucyk cultivars (19–21%). The increase in grain yield at a high sowing rate was the result of a bigger number of ears per unit of area in all cultivars (especially in the Basic and Raskud cultivars). The difference in the weight of 1000 grains and the number of grains per ear of the investigated varieties as a consequence of the sowing rate was negligible. In the years 2012–2013, there occurred an increase in the protein content of grains at a high sowing rate. Among all the cultivars (on average considering the sowing rate), the highest grain yields were produced by Iron and Ella, the highest density of the number of ears per unit of area was demonstrated by Natasia, Kucyk and Ella. The cultivars Iron, Gawrosz and Raskud were found to have a significantly higher number of grains per ear than the remaining cultivars.

Keywords: spring barley, sowing rate, cultivar, grain yield, yield components, protein content

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INTRODUCTION

In the study on the influence of various crop management-related factors on the yielding of spring barley, it was found that the sowing rate is a factor that strongly interacts with other factors within the scope of grain yield and its yield components (Noworolnik, 2003, 2012; Żuk-Gołaszewska, 2008). There exists a clear interaction between the sowing rate applied and the varieties of spring barley (Jedel, Helm, 1995; Kozłowska-Ptaszyńska, 1993; Kozłowska-Ptaszyńska, Pecio, 1999; Noworolnik, 2007, 2008, 2010, 2015; Noworolnik, Leszczyńska, 1998, 2000, 2004b; Pecio, 1995). This is related to the varying tillering capacity of cultivars and to the different light requirements. The large number of new varieties of spring barley recently introduced into cultivation justifies the purpose of testing their requirements regarding the optimal sowing rate in relation to grain yield.

The aim of the study was to determine the response of new cultivars of spring barley in terms of grain yield, yield components and protein content in grains, to an increase in the sowing rate. It is also important to compare the varieties in terms of productive tillering capacity and the number of grains per ear because these characteristics are not determined by COBORU (the Research Centre for Cultivar Testing). The research hypothesis assumed a heterogeneous influence of the sowing rate on the yield of respective barley cultivars. Cultivars, whose tillering capacity is naturally smaller should respond more positively to an increase in their sowing rate.

MATERIAL AND METHODS

Microplot experiments with spring barley were carried out under partially controlled conditions (protection against lodging, drought and diseases) at the IUNG-PIB experimental field in Puławy, in which 3 sowing rates were studied: 250, 350 and 450 grains m^{-2}. In the years 2011–2012, the following cultivars were investigated: Basic, Goodluck, Iron, KWS Olof, Natasia, and in the years 2012–2013 cultivars: Despina, Ella, Fariba, Gawrosz (hulless variety), Kucyk and Raskud. The experiments were carried out on a soil of the good wheat complex (heavy loamy sand deposited on light loam), in a field previously cropped to potatoes, using the split-block design (factor I – cultivars, factor II – sowing rate), in 4 replications (plot area – 1 m^2), from the 3rd to the 10th of April. The soil was rich in phosphorus, potassium and magnesium. Before sowing, the following fertilization was used: 60 kg N, 22 kg P and 58 kg K ha^{-1}. Barley was sown by hand, with the row spacing of 11 cm at a rate greater than normally recommended, and after germination, thinning was conducted to obtain the appropriate plant density (according to the experiment layout). Plants were mechanically secured against lodging (pegs, cords) during the growing period (because the mechanical method is more effective than using retardants). Weed control was carried out manually (twice) and diseases and pests were eradicated using chemical agents. During shortages of rainfall, the plots were watered. The barley was harvested by hand, at its full maturity, from the entire plot. During the harvest, plants and ears were counted and the number of plant losses (at their missing spots in rows) was determined, including the number of sterile plants. The productive tillering coefficient was calculated by dividing the number of ears by the number of plants after germination. After the harvest of barley, the grain yield (in terms of weight, number per plot), the total protein content in a grain were determined (using the Kjeldahl method). The weight of 1000 grains was determined on the basis of grain samples collected from the plot (4 × 100 grains), and the number of grains per ear – as the average from a sample of 100 ears. The results were analysed statistically using the two-way ANOVA test, and the significance of differences for the values averaged across the experiment years was measured using Tukey's test ($p = 0.05$) using. The significance of the differences in Tables 3–6 was calculated based on individual variance analyses for each cultivar.

RESULTS AND DISCUSSION

A significant influence of the sowing rate on the yield of spring barley (averaged across cultivars), the number of ears per m^2 and the protein content in a grain were found (Table 1, 2). A significant increase in the grain yield was obtained as the sowing rate was increased from 250 to 350 and 450 grains m^{-2} in both series of experiments. This was a result of the significant increase in the number of ears of the investigated cultivars per unit of area under the influence of the increase in the sowing rate of barley. The variability of an ear's productivity (also averaged across cultivars) under the influence of the sowing rate was negligible, however, there was a tendency towards a greater number of grains per ear at a sowing rate of 250 grains m^{-2} (Table 1) and a higher weight of 1000 grains at this sowing rate (Table 2). At the highest sowing rate (450 grains m^{-2}), there occurred an increase in plant loss and a reduction in the productive tillering coefficient of barley plants.

All the cultivars demonstrated a significant increase in grain yield (Tables 3, 4) and a significant increase in the num-

Table 1. Grain yield, yield components and protein content in grain of spring barley (mean of cultivars) depending on sowing rate (2011–2012).

Sowing rate [seed number per 1 m^2]	Grain yield g m^{-2} [%]	Ear number per 1 m^2 [%]	Plant losses [%]	Productive tillering coefficient	Grain number per ear	1000 grain weight [g]	Protein content in grain [d.m. %]
250	786 [100]c	792 [100] c	4.1	3.3	19.6 a	50.0 a	11.1 a
350	888 [113] b	975 [123] b	5.5	3.0	18.4 a	49.4 a	11.1 a
450	939 [119] a	1074 [136]a	7.6	2.5	18.3 a	48.2 a	11.4 a

Values in the same column followed by different letters are significantly different

Table 2. Grain yield, yield components and protein content in grain of spring barley (mean of cultivars) depending on sowing rate (2012–2013).

Sowing rate [seed number per 1 m^2]	Grain yield g m^{-2} [%]	Ear number per 1 m^2 [%]	Plant losses [%]	Productive tillering coefficient	Grain number per ear	1000 grain weight [g]	Protein content in grain [d.m. %]
250	810 [100]c	834 [100] c	2.2	3.4	19.9 a	49.2 a	11.1 b
350	954 [118] b	1005 [120] b	3.4	3.0	19.8 a	48.2 a	11.3 ab
450	1014 [125] a	1110 [133] a	6.0	2.6	19.6 a	46.8 a	11.7 a

Values in the same column followed by different letters are significantly different

ber of ears per unit of area (Tables 5, 6) at a sowing rate of 350 grains m^{-2}, as opposed to the sowing rate of 250 grains m^{-2}. At a high sowing rate (450 grains m^{-2}) a significant increase in the grain yield of the following cultivars occurred: Basic, Iron, Despina and Gawrosz, and the increase in other cultivars at this sowing rate, as opposed to the sowing rate of 350 grains m^{-2}, constituted a trend. The biggest increases in yields at a high sowing rate (450 grains m^{-2}), as opposed to a low sowing rate (250 grains m^{-2}, were demonstrated in the first series of experiments (2011–2012) by the following cultivars: Iron (29%), Basic (25%) and Goodluck (21%), and lower increases were demonstrated by: KWS Olof (13%) and Natasia (10%). In the second series (2012–2013), bigger increases in yields at a high sowing rate, as opposed to a low sowing rate, were demonstrated by the following cultivars: Gawrosz, Raskud and Despina (31–34%), and lower increases were demonstrated by the Ella, Fariba and Kucyk cultivars (19–21%) (Tables 3, 4). The highest increase in the number of ears per unit of area at a high sowing rate, as opposed to a low sowing rate (52%), was shown by the following cultivars: Basic (2011–2012) and Raskud (2012–2013). The lowest increases in the number of ears at a high sowing rate were observed in the cultivars Natasia and Goodluck (25–28%, 2011–2012), as well as Kucyk (21%, 2012–2013) (Tables 5, 6).

Previous reports by other authors lack information on the comparison of the responses of the latest spring barley cultivars to given sowing rates. In the relevant literature, such information is related only to the results of microplot experiments conducted permanently at IUNG-PIB in Puławy (Noworolnik, 2007, 2008, 2010, 2015; Noworolnik, Leszczyńska, 1998, 2000, 2004b; Pecio, 1995) for cultivars older than those investigated in the present work. It was noted that cultivars with a smaller tillering capacity

Table 3. Grain yield [g m^{-2}] of spring barley cultivars depending on sowing rate (2011–2012).

Sowing rate [seed number per 1 m^2]	Cultivars				
	Basic	Goodluck	Iron	KWS Olof	Natasia
250	768 c	702 b	825 c	780 b	855 b
350	894 b	813 a	978 b	852 a	906 a
450	963 a	846 a	1062 a	879 a	942 a

Calculate separately for each cultivar; Values in the same column followed by different letters are significantly different.

Table 4. Grain yield [g m^{-2}] of spring barley cultivars depending on sowing rate (2012–2013).

Sowing rate [seed number per 1 m^2]	Cultivars					
	Despina	Ella	Fariba	Gawrosz	Kucyk	Raskud
250	807 c	906 b	828 b	705 c	876 b	735 b
350	966 b	1029 a	954 a	831 b	993 a	951 a
450	1059 a	1074 a	1005 a	943 a	1029 a	975 a

Calculate separately for each cultivar; Values in the same column followed by different letters are significantly different.

Table 5. Ear number per 1 m^2 of spring barley cultivars depending on sowing rate (2011–2012).

Sowing rate [seed number per 1 m^2]	Cultivars				
	Basic	Goodluck	Iron	KWS Olof	Natasia
250	720 c	801 c	796 c	789 b	857 c
350	939 b	954 b	978 b	1005 a	1020 b
450	1092 a	1023 a	1103 a	1056 a	1096 a

Calculate separately for each cultivar; Values in the same column followed by different letters are significantly different.

Table 6. Ear number per 1 m^2 of spring barley cultivars depending on sowing rate (2012–2013).

Sowing rate [seed number per 1 m^2]	Cultivars					
	Despina	Ella	Fariba	Gawrosz	Kucyk	Raskud
250	828 b	933 c	912 c	708 c	948 b	675 c
350	1020 a	1086 b	1071 b	822 b	1074 a	894 b
450	1155 a	1164 a	1149 a	1014 a	1143 a	1029 a

Calculate separately for each cultivar; Values in the same column followed by different letters are significantly different.

demonstrated higher grain yields at a high sowing rate. A large increase in the number of ears per unit of area in some cultivars under the influence of an increased sowing rate generally results in a greater drop in the weight and number of grains per ear. The heterogeneous response of spring barley cultivars to the sowing rate due to the different properties of cultivars was also demonstrated in field experiments carried out in Poland (Kozłowska-Ptaszyńska, Pecio, 1999; Pecio et al., 2000; Noworolnik, 2007; Noworolnik, Leszczyńska, 2004a) and abroad (Jedel, Helm, 1995). The lack of a positive response of spring barley to a high sowing rate (above 400 grains per m^2) in field experiments (as opposed to the controlled conditions in microplot experiments) ought to be explained by the occurrence of partial lodging of plants and by a greater incidence of diseases in conditions where the stand density was too high (Noworolnik, 2003).

Small changes in the protein content in seeds of the studied cultivars were noted under the influence of an increased sowing rate (Tables 1, 2). Negligible variation of the protein content of the spring barley grain occurred in 2011–2012, while an increase in the value of this feature under increased sowing rate was obtained in 2012–2013. Small but varying changes in the protein content of seeds of the investigated cultivars under an increased sowing rate were also found in other studies (Bertholdsson, 1999; Eagles et al., 1995; Noworolnik, 2007, 2008, 2015; Pecio 2002; Pecio et al., 2000; Szmigiel, Oleksy, 1998; Żuk-Gołaszewska, 2008). High grain yields increases correspond here to the lower increases in the protein content of barley grain. Many studies also point to a small decrease in WTS (Jedel, Helm, 1995; Noworolnik, 2007, 2008, 2010, 2015; Pecio, 1995, 2002) under the influence of an increased sowing rate.

Large variability in the grain yield was found among cultivars of spring barley in both series of experiments (Table 7, 8). The Iron cultivar yielded significantly higher than: Basic, Goodluck and KWS Olof cultivars in the years 2011–2012. The yield of Goodluck was the lowest. In the second series of experiments (2012–2013), Ella yielded significantly higher than the other cultivars, with Gawrosz and Raskud characterized by the lowest yield. The lower yielding of the hulless barley cultivar in comparison to the hulled ones was also found in Liszewski's research (2008). Among grain yield components, the greatest diversity among spring barley cultivars was related to the number of ears per unit of area. In the first series of experiments (2011–2012), the highest number of ears per 1 m^2 and the highest productive tillering coefficient pertained to Natasia, while the lowest pertained to Basic and Goodluck (Table 7). In the second series of experiments (2012–2013): Kucyk and Ella were the ones that produced a significantly larger number of ears per 1 m^2 compared to the other cultivars (Table 8). The lowest productive tillering capacity was shown by Raskud and the hull-less Gawrosz.

The number of grains per ear of the studied cultivars in the first series of experiments varied significantly (Table 7). The highest value of this feature was shown by Iron, and the lowest value, by Goodluck. Among the cultivars in the second series of experiments, a significantly highest number of grains per ear was noted for Gawrosz and Raskud and the lowest ones for Kucyk, Despina and Ella (Table 8).

Table 7. Comparison of grain yield and yield components of spring barley cultivars (mean of sowing rates) (2011–2012).

Specification	Cultivars				
	Basic	Goodluck	Iron	KWS Olof	Natasia
Grain yield [g m^{-2}]	875 bc	787 d	955 a	837 cd	901 ab
Ear number per 1 m^2	917 b	926 b	957 ab	950 ab	991 a
Productive tillering coefficient	2.6	2.7	2.9	2.9	3.2
Grain number per ear	19.1 b	16.9 c	21.0 a	18.4 b	18.5 b
1000 grain weight [g]	50.7 a	50.3 a	47.4 b	48.4 ab	50.0 a
Protein content in grain [d.m. %]	11.4 a	11.7 a	10.8 b	11.5 a	10.7 b

Values in the same lines followed by different letters are significantly different

Table 8. Comparison of grain yield and yield components of spring barley cultivars (mean of sowing rates) (2012–2013).

Specification	Cultivars					
	Despina	Ella	Fariba	Gawrosz	Kucyk	Raskud
Grain yield [g m^{-2}]	945 b	1029 a	930 bc	825 d	966 b	888 c
Ear number per 1 m^2	1002 bc	1062 a	1044 ab	865 c	1056 a	867 c
Productive tillering coefficient	3.0	3.4	3.2	2.6	3.3	2.7
Grain number per ear	19.0 b	19.2 b	19.9 ab	20.8 a	18.7 b	20.9 a
1000 grain weight [g]	49.8 a	49.3 a	44.8 b	45.8 b	49.1 a	49.6 a
Protein content in grain [d.m. %]	11.2 bc	10.8 c	11.3 bc	12.1 a	11.6 ab	11.6 ab

Values in the same lines followed by different letters are significantly different

The highest weight of 1000 seeds was demonstrated by the following cultivars: Basic, Goodluck, Natasia, Despina, Ella, Kucyk and Raskud. The significantly highest protein content in a grain was recorded for Gawrosz, followed by Basic, Goodluck and KWS Olof, Kucyk and Raskud cultivars. The lowest protein content in a grain was demonstrated by the following cultivars: Iron, Natasia and Ella (Tables 7, 8). The results of the assessment of cultivars are original in terms of the productive tillering coefficient and the number of grains per ear because these features are not studied by COBORU (the Research Centre for Cultivar Testing).

SUMMARY

A diverse response with regard to the yield of the studied spring barley cultivars depending on the applied sowing rates was demonstrated. The sowing rate of 450 grains m^{-2} was the most productive for the cultivars: Basic, Iron, Despina and Gawrosz. In the case of cultivars: Goodluck, Natasia, Ella, Fariba, Kucyk and KWS Olof, as well as Raskud, the sufficient sowing rate is 350 grains m^{-2}. An increase in the sowing rate had a significant effect on the number of productive ears, while no such effect on the number of grains per ear and the weight of 1000 grains was proved. The sowing rate caused the protein content in grain to vary significantly in only one of the series of experiments. Among the compared cultivars, the highest yield was obtained by Ella, which produced the highest stand density and grains characterized by high weight of 1000 grains. The grain of the hull-less Gawrosz cultivar was the richest in proteins.

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