CHILEANJAR
CHILEAN JOURNAL of AGRICULTURAL RESEARCH

RESEARCH

Effect of seeding rate on grain quality of winter wheat

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Planting density is important factor which influence yield and quality of wheat (*Triticum aestivum* L.) For this reason, in scientific investigations is constantly investigated optimization of plant number per unit area. The objective of this study was to determine the influence of seeding rate in grain quality of winter wheat cultivars. The experiment was conducted with four winter wheat genotypes ('Ana Morava', 'Vizija', 'L-3027', and 'Perla') at the Small Grains Research Centre of Kragujevac, Serbia, in 3 yr at two seeding rates (SR1 = 500 and SR2 = 650 germinating seeds m^{-2}). The 1000-kernel weight, Zeleny sedimentation, and wet gluten content in divergent wheat genotypes were investigated depending on the seeding rate and ecological factors. Significant differences in quality components were established between investigated seeding rates. The highest values of all investigated quality traits were established in SR2 variant when applied 650 seeds m^{-2}. Genotypes reacted differently to seeding rate. 'Perla' in average had the highest mean sedimentation value (42.2 mL) and wet gluten content (33.76%) in SR2 variant and this cultivar responded the best to seeding rate. Significant differences for sedimentation value and wet gluten content were found among cultivars, years, seeding rate, and for all their interactions. Also, ANOVA for 1000-kernel weight showed highly significant differences among investigated varieties, seeding rate and growing seasons, but all their interactions were not significant. In all investigated genotypes, better quality was established in SR2 variant when applied 650 seeds m^{-2}.

Key words: Gluten content, 1000-kernel weight, *Triticum aestivum*, Zeleny sedimentation.

INTRODUCTION

Wheat (*Triticum aestivum* L.) is one of the most important cultivated crops, being grown in a wide range of environments that affect overall performance, particularly grain yield and end-use quality. Wheat yield and end-use quality depend upon the environment, genotype, and their interaction. Grain yield and quality of winter wheat are affected by several factors, and crop management has a very important role among them. For achieving high yields and grain quality of wheat it is important to apply all the cultural practices completely and on time and adapt them to cultivars. The correct fertilizer application, particularly N is very important to achieve high yields and good grain quality of wheat. Besides regular nutrition of plants for achieving high yields and good quality, sowing time and planting density play an important role. Optimum plant densities vary greatly between areas, climatic conditions, soil, sowing time, and varieties. Since cultivars genetically differ for yield components, individual cultivars need to be tested at a wide range of seeding rates to determine their optimum seeding rate (Wiersma, 2002).

Management practices play an important role in determining yield and end-use quality of wheat. Numerous studies have documented how N fertilization (Campillo et al., 2010; Hirzel et al., 2010; Zecevic et al., 2010; Nikolic et al., 2012), seeding rate, planting date, row spacing, and seeding depth affect yield and yield components of wheat (Wajid et al., 2004; Guberac et al., 2005; Schillinger, 2005; Kristó et al., 2007; Maric et al., 2008; Otteson et al., 2008; Valério et al., 2009). Seeding rates for winter wheat can vary widely due to differences in seed quality, planting conditions, planting dates and planting equipment (Lloveras et al., 2004).

New wheat varieties are more productive and some of them are of higher quality than the old ones. Therefore, their total technological requirements, planting density being one of them, are diverse, due to which they need to be continuously examined for determining their requirements in specific conditions (Bokan and Malesevic, 2004; Caglar et al., 2011).

The objective of this study was to determine the influence of seeding rate in grain quality of winter wheat cultivars.

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Received: 18 April 2013.
Accepted: 1 December 2013.
doi:10.4067/S0718-58392014000100004

MATERIALS AND METHODS

Four winter wheat genotypes ('Ana Morava', 'Vizija', 'L-3027', and 'Perla') were grown during three years (2004/2005, 2005/2006 and 2006/2007) at experimental field of Small Grains Research Centre of Kragujevac Serbia (44°01'12" N, 20°55'12" E, 185 m a.s.l.) The field experiment was performed on the soil belonging to the Smonitza (Vertisol) type, with a relatively high clay content and unfavorable physical properties. The content of humus in the surface layer of soil is medium (2.51%), and substitutional and total hydrolytic acidity are quite high (pH H_2O = 5.16, and in KCl = 4.91). The soil is well provided with total N (0.16% N) and easily available K (29.2 mg 100 g^{-1} soil K_2O), and poor in available P (17.6 mg 100 g^{-1} soil P_2O_5).

The field experiment was conducted in a randomized block design with three replicates with plot of 5 m^2. Two seeding rates were compared: SR1 = 500 and SR2 = 650 germinating seeds m^{-2}. Experiment was carried out by the standard technology of scientific farming production of wheat. Spring field pea (*Pisum sativum* L.) was used as the preceding crop in all study years. Sowing was carried out at optimal time (from 10-15 October). Whole P and K and half of N (300 kg ha^{-1} NPK) was applied at sowing time and remaining N was applied after hibernation at the tillering stage in early spring in the form of KAN fertilizer (90 kg N ha^{-1}).

Average 1000-kernel weight was determined by counting and weighing samples of two times of 500 kernels and then found values were averaged and multiplied by two.

Grain samples were milled using a laboratory mill (Quadrumat Junior, Brabender, Duisburg, Germany). The quality analysis of Zeleny sedimentation test and wet gluten content were done by International Association for Cereal Chemistry (ICC) standard methods nr 116/1 and 106/2, respectively (ICC, 1972).

Data were subjected to ANOVA as randomized complete block design with three main factors (genotype, year, and seeding rate) using MSTAT-C statistical software. The significant differences between means were grouped according to least significant difference (LSD).

Climatic conditions during the experiment

Climatic conditions during the experiment and long-term period are shown in Table 1. Average temperatures were similar during first (8.5 °C) and second (8.3 °C) investigated years, which also were similar according to the long-term period (8.5 °C). In 2007, average temperature was higher than in the both previous years and long-term period. Mainly differences were in the winter period when plants were in hibernation that did not influence significantly plant growing.

Sums of precipitation were higher in 2005 (490.8 mm) and 2006 (533.7 mm) than in 2007 (369.9 mm) investigated year. According to long-term period, precipitations in 2006/2007 vegetative period were lower than 47.9 mm, while in 2004/2005 and 2005/2006 were higher (73.0 and 115.9 mm, respectively). In May 2007, precipitations were higher in relation with other two investigated years and long-term period, but in drought period of April 2007 it was only 3.6 mm, which negatively influenced plant growing.

RESULTS AND DISCUSSION

These results showed that higher seeding rate has a positive effect on wheat grain quality. Higher density provides a greater number of primary tillers per square meter, which causes the formation of grains with larger size and mass. These grains have a more favorable ratio of storage proteins and starch, which requires better quality. In crops with a lower density, a greater number of secondary tillers is created, which produce small grains with less weight and lower quality. These results agree with those of Geleta et al. (2002), and may have been caused by the presence of additional secondary tillers that delayed maturity and reduced kernel uniformity at lower seeding rates. The later tillers produce smaller grains which result in low grain volume weight.

The 1000-kernel weight varied significantly between varieties, growing seasons and seeding rate (Table 2). Higher sowing rate (SR2) resulted in increasing of 1000-kernel weight (2.4%), sedimentation value (28.5%) and wet gluten content (6.8%). In average for all varieties

Table 1. Monthly temperature and monthly precipitation for the three growing seasons (2004-2007) and long-term period (1990-2000).

	Temperature				Precipitation			
Month	2004/2005	2005/2006	2006/2007	1990/2000	2004/2005	2005/2006	2006/2007	1990/2000
	ºC				mm			
Oct	14.7	11.5	13.3	11.83	50.1	49.0	16.7	61.02
Nov	6.8	5.6	7.6	6.4	121.3	54.8	13.7	44.29
Dec	3.0	3.3	3.5	1.71	19.7	47.1	51.9	44.65
Jan	1.5	-1.7	6.1	-0.1	36.6	27.9	45.3	30.04
Feb	-1.5	1.5	6.3	2.62	66.9	38.1	32.1	29.87
Mar	4.5	5.6	9.1	5.99	43.6	116.1	62.9	33.21
Apr	11.6	12.7	12.1	11.6	43.3	86.3	3.6	52.88
May	16.4	16.4	18.2	16.37	70.2	29.6	118.4	52.57
June	19.2	19.7	22.8	20.37	39.1	84.8	25.3	69.28
$\bar{x}/\sum$	8.5	8.3	11.0	8.5	490.8	533.7	369.9	417.8

Table 2. Mean values for 1000-kernel weight.

Year (B)	Seeding rate (C)	Genotype (A) Ana Morava	Vizija	L-3027	Perla	$\bar{x}$ B	
		g					
2005	SR1	42.00fghij	46.55ab	39.20k	41.52ghij	42.32	42.71ab
	SR2	42.80efgh	46.60ab	40.85hijk	42.15efghi	43.10	
2006	SR1	43.10efg	46.15ab	41.32ghij	42.20efgh	43.19	43.81a
	SR2	44.05cde	47.65a	42.33efgh	43.65def	44.42	
2007	SR1	41.33ehij	45.55bcd	40.00jk	40.17ijk	41.76	42.30b
	SR2	42.36efgh	45.80abc	41.52ghij	41.67fghij	42.84	
$\bar{x}$A		42.61b	46.38a	40.87c	41.89bc	42.94	
$\bar{x}$SR1 (A)		42.14	46.08	40.17	41.30	42.42	
$\bar{x}$SR2 (A)		43.07	46.68	41.57	42.49	43.45	

SR1: 500 seeds m^{-2}, SR2: 650 seeds m^{-2}.
Distinct letters in the row indicate significant differences according to LSD test ($P \leq 0.05$).

and years higher 1000-kernel weight established in SR2 (43.45 g) than in SR1 variant (42.42 g). The mean 1000-kernel weight was the highest in 'Vizija' (46.38 g), which differed significantly from all other varieties. The lowest mean for this trait was established in L-3027 (40.87 g). In all investigated years SR2 variant induced higher 1000-kernel weight and the highest mean value established in the 2006 year (44.42 g). The lowest average value was determined with SR1 variant in 2007 year (41.76 g).

The ANOVA for 1000-kernel weight showed highly significant differences among investigated varieties, seeding rate and growing seasons, but all their interactions were not significant (Table 5). The strongest individual influence for 1000-kernel weight were variety ($F = 102.60^{**}$) and seeding rate ($F = 18.76^{**}$), but the lowest interaction was year × seeding rate ($F = 0.30^{ns}$). Correlation analyses showed that 1000-kernel weight correlated positively with Zeleny sedimentation and wet gluten content ($r = 0.140$ and $r = 0.210$, respectively).

In these studies, 1000-kernel weight was increased with increasing seeding rate in all genotypes and investigated years. Changes in seeding density have special importance in wheat crops since they have a direct effect on grain yield and its components (Lithourgidis et al., 2006; Ozturk et al., 2006) according to the cultivation environment (Lloveras et al., 2004).

The seeding rate induced increase in 1000-kernel weight in all study years. On the other hand, there are results showing that higher seeding rate decreased 1000-kernel weight (Spink et al., 2000; Baloch et al., 2010; Laghari et al., 2011). Several authors emphasized the influence of sowing density on the number of fertile tillers per square meter and 1000-kernel weight (Hiltbrunner et al., 2005; Dubis and Budzyński, 2006). They established that with seeding rate of 600 in compare to 480 seeds m^{-2} increased number of spikes m^{-2}, number of grains per spike, but 1000 grain weight and coefficient of productive tillering decreased. Valério et al. (2009) established that low tillering ability genotypes showed a closer association of number of fertile tillers with grain yield. However, an inverse association was found between number of fertile tillers and weight of 1000-grains. Effects of seed rate on 1000-grain weight and grain specific weight were small and inconsistent (Gooding et al., 2002). Also, the highest kernel yield was achieved with sowing rate 600 germinable seeds m^{-2} (Kristó et al., 2007; Maric et al., 2008). On the other hand, various sowing rates had highly significant influence on the number of fertile tillers (Khaliq et al., 1999; Chaudhry and Hussain, 2001; Wajid et al., 2004), and that sowing rate influences mainly of number of spikes per square meter, which has the closest relationship to yield from all yield components (Spink et al., 2000; Guberac et al., 2000; Lloveras et al., 2004; Stougaard and Xue, 2004; Guberac et al., 2005; Lithourgidis et al., 2006; Ozturk et al., 2006).

In our studies, for 1000-kernel weight significant differences among cultivars, years and seeding rate were identified, but interactions were not significant. Results are in accordance with the findings of Geleta et al. (2002). They pointed out that seeding rate is a predictable environmental factor that affects some agronomic and end-use quality traits of wheat; therefore, it should be studied carefully to obtain higher grain yields with better end-use quality. Lloveras et al. (2004) and Otteson et al. (2007) established that kernel weight was significantly affected by environment and variety, but not by seeding rate.

Zeleny sedimentation in average for all years and seeding rate was the highest in 'Perla' (42.2 mL), which differed significantly from all other varieties; the lowest sedimentation value was found in 'L-3027' (25.8 mL) and in average for all varieties and years higher sedimentation value was establish in SR2 (37.0 mL) than in SR1 seeding rate (28.8 mL) (Table 3).

Correlation coefficient between Zeleny sedimentation and wet gluten content was positive ($r = 0.496$). Both of these quality components directly depend on grain protein content, especially by storage protein components. With increasing seeding rate, gluten content increased in all investigated years and varieties (Table 4). Wet gluten content was the highest in 'Perla' (33.76%) in average for all varieties, seeding rates, and years, and the lowest in 'L-3027' (26.23%) (Table 4). In average, for all varieties and years higher sedimentation value was established in SR2 (32.26%) than in SR1 seeding rate (30.22%).

Table 3. Mean values for Zeleny sedimentation.

Year (B)	Seeding rate (C)	Genotype (A)				$\bar{x}$ B	
		Ana Morava	Vizija	L-3027	Perla		
		mL					
2005	SR1	26.0ijkl	29.0ghij	25.0klm	31.3efgh	27.8	34.1a
	SR2	33.0def	34.0de	32.7defg	62.0a	40.4	
2006	SR1	25.7jkl	28.3hijk	22.7lm	35.7d	28.1	31.2b
	SR2	32.3defg	35.3d	29.7fghi	39.7c	34.2	
2007	SR1	32.0defgh	34.7de	21.7m	33.7de	30.5	33.4ab
	SR2	31.3efgh	40.0c	23.0lm	50.7b	36.2	
$\bar{x}$A		30.0c	33.6b	25.8d	42.2a	32.9	
$\bar{x}$SR1 (A)		27.9	30.7	23.1	33.6	28.8	
$\bar{x}$SR2 (A)		32.2	36.4	28.5	50.8	37.0	

SR1: 500 seeds m^{-2}, SR2: 650 seeds m^{-2}.
Distinct letters in the row indicate significant differences according to LSD test ($P \leq 0.05$).

Table 4. Mean values for wet gluten content.

Year (B)	Seeding rate (C)	Genotype (A)				$\bar{x}$ B	
		Ana Morava	Vizija	L-3027	Perla		
		%					
2005	SR1	32.58efgh	34.77abcd	25.56l	33.25cdefg	31.54	32.23a
	SR2	34.25abcde	35.25abc	28.00jk	34.15bcde	32.91	
2006	SR1	30.70hi	29.80ij	26.25kl	31.22ghi	29.49	
	SR2	34.13bcde	30.58hi	26.85kl	32.05fgh	30.90	30.20b
2007	SR1	33.78bcdef	25.91l	23.21m	35.68ab	29.64	
	SR2	35.17abc	32.87defg	27.50kl	36.24a	32.94	31.30ab
$\bar{x}$A		33.44a	31.52b	26.23c	33.76a	31.24	
$\bar{x}$SR1 (A)		32.35	30.16	25.01	33.38	30.22	
$\bar{x}$SR2 (A)		34.52	32.90	27.45	34.15	32.26	

SR1: 500 seeds m^{-2}, SR2: 650 seeds m^{-2}.
Distinct letters in the row indicate significant differences according to LSD test ($P \leq 0.05$).

ANOVA revealed highly significant differences among investigated varieties, seeding rates and growing seasons as well as highly significant all their interactions for both sedimentation value and wet gluten content (Table 5). The strongest individual influence for sedimentation value had seeding rate ($F = 330.24^{**}$) and variety ($F = 239.52^{**}$), but the lowest investigated year ($F = 15.61^{**}$). For wet gluten content, the strongest individual influence had variety ($F = 210.73^{**}$) and seeding rate ($F = 71.41^{**}$), but the lowest their interaction ($F = 3.32^{*}$). Seeding rate had the greatest impact on Zeleny sedimentation compared to the other two investigated traits of grain quality of wheat. Wet gluten content and 1000-kernel weight greatly influenced by variety and less so by seeding rates. However, sedimentation value was greatly influenced by seeding rates than by varieties.

More researchers investigated the effect of planting density on yield and yield components than on grain quality. Olaru et al. (2008) reported that wheat quality components were influenced by the seed rate; wet gluten content increased with the reduction of seed rate, while Zeleny index achieved higher values at higher seeding rate (550 grains m^{-2}). Otteson et al. (2008) point out that seeding rate did not result in a significant change in grain quality or milling and baking quality. Overall, genotype was the most important factor in determining grain quality and milling and baking performance. According to Caglar et al. (2011) seeding rates had significant impacts on yield and quality parameters of wheat. They found out that seeding rate of 325 seeds m^{-2} was suitable for flour yield, but 526-625 seeds m^{-2} like dense seeding rates had better effects over other parameters (sedimentation volume, wet gluten content, dry gluten content, and flour ash content).

Table 5. ANOVA for investigated wheat quality characteristics.

Source	DF	1000-kernel weight		Zeleny sedimentation		Wet gluten content	
		MS	F	MS	F	MS	F
Genotype (A)	3	104.09	102.60^{**}	870.70	239.52^{**}	218.37	210.73^{**}
Year (B)	2	14.56	14.35^{**}	56.76	15.61^{**}	24.75	23.88^{**}
A×B	6	1.16	1.15^{ns}	68.41	18.82^{**}	22.89	22.09^{**}
Seeding rate (C)	1	19.03	18.76^{**}	1200.50	330.24^{**}	73.99	71.41^{**}
A×C	3	0.53	0.52^{ns}	165.65	45.57^{**}	3.45	3.32^{*}
B×C	2	0.31	0.30^{ns}	88.04	21.22^{**}	7.29	7.03^{**}
A×B×C	6	0.39	0.38^{ns}	75.58	20.79^{**}	6.59	6.36

*Significant at $P = 0.05$ level; **significant at $P = 0.01$ level; ^{ns}: non significant.

In our investigation significant differences among cultivars, years, seeding rate, and their interactions were identified for sedimentation value and wet gluten content. These results agree with findings of Geleta et al. (2002), who reported significant differences among environments, seeding rates, genotypes, and some of their interactions. They found out that lower seeding rates decreased plant population, grain yield, kernel weight, flour yield, mixing time, caused later flowering, and increased flour protein content and mixing tolerance. Similar results were obtained Hiltbrunner et al. (2005), who established that grain yield was not decreased by wider row spacing, 1000-kernel weight and grain protein content were increased from 42.6 to 43.5 g and from 11.7% to 12.7%, respectively, compared to the narrow row spacing.

In this study, correlation coefficient between Zeleny sedimentation and wet gluten content was positive (r = 0.496), what agree with previous results established (Zecevic et al., 2004; Aydin et al., 2010; Tayyar, 2010).

Bokan and Malesevic (2004) concluded that planting density of winter wheat varieties, at an optimal planting date, should amount to 600 germinating kernels m^{-2}, thus producing a sufficient number of good-quality spikes with adequate yield structure. Plants compensated for low population densities by increasing production and survival of tillers and, to a lesser extent, increasing grain numbers per ear. Schillinger (2005) point out that grain yield in spring wheat was not affected by sowing rate because increased number of heads per unit area and kernels per head consistently compensated for reduced plant stand density.

The optimal seeding rates vary from year to year and depending on growing seasons (Caglar et al., 2011) and grain-filling periods. Seeding rates in wheat can vary widely due to differences in seed quality, planting conditions, planting dates, and planting equipment or system being used. The results suggest that lower seeding rates may be adequate under excellent growing conditions (Lloveras et al., 2004). Seeding rate should be considered as a factor in obtaining higher grain yield with good end-use quality (Geleta et al., 2002). Optimum seeding rates for grain yield of winter cereals may be higher when seeding is delayed past the optimum date of seeding. High seeding rates increase early DM accumulation and weed competitiveness, but may have negligible or negative impacts on grain yield due to increased inter-plant competition (Park et al., 2003).

CONCLUSIONS

Investigated quality parameters (1000-kernel weight, sedimentation value and wet gluten content) varied significantly between varieties, growing seasons and sowing densities. Higher sowing rate (SR2) increased 1000-kernel weight (2.4%), sedimentation value (28.5%), and wet gluten content (6.8%). Seeding rate had the greatest impact on Zeleny sedimentation compared to the other two investigated traits of wheat grain quality.

Optimum seeding rate for winter wheat is environment-specific because of soil quality, water content, and winter survival. These results have shown that planting density of winter wheat, at an optimal planting date, should be about 650 germinating seeds m^{-2}, what will produce a sufficient number of good-quality spikes with adequate yield structure and quality.

ACKNOWLEDGEMENTS

This work was supported by the Ministry of Education, Science and Technological Development of the Republic of Serbia within the Project of technological development nr TR 31031 and TR 31092.

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