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Yield components and quality parameters of winter wheat depending on tillering coefficient

Z. Gaile[1,*], A. Ruza[1], D. Kreita[1] and L. Paura[2]

[1]Latvia University of Agriculture, Faculty of Agriculture, Liela street 2, LV–3001, Jelgava, Latvia
[2]Latvia University of Agriculture, Faculty of Information Technologies, Liela street 2, LV–3001, Jelgava, Latvia
[*]Correspondence: zinta.gaile@llu.lv

Abstract. Winter wheat (*Triticum aestivum* L.) is the main and most profitable cereal crop in Latvia, thus different aspects of its growth are widely researched. The aim of this three-year (2004–2005 and 2006–2007) long investigation arranged at Research and Study farm 'Peterlauki' of Latvia University of Agriculture (56° 30.658′ N and 23° 41.580′ E) was to evaluate importance of tillering for wheat yield, yield components and quality formation alongside the effect of cultivar, sowing date and rate, and research year. Three cultivars ('Cubus', 'Tarso', 'Zentos'), four sowing dates (starting with 30 August ± 2 days with 10-day intervals) and three sowing rates (300, 400 and 500 germinable seeds m^{-2}) were used. Soil and crop management was appropriate. Yield components were detected from sample sheets. Yield was affected substantially ($p < 0.05$) by all the investigated factor except sowing rate. Plants with tillering coefficient (TC) '1' to '6' formed yield, and the biggest proportion (20%) was given by plants with TC '3'. Grain number and weight per spike was substantially ($p < 0.01$) affected by TC, but changes in their values were irregular and further investigations are needed. Average values of crude protein, gluten and starch content, Zeleny index and 1,000 grain weight was not affected by TC substantially. Thus, tillering was found beneficial for winter wheat yield formation as part of yield compensation mechanism. Sowing rate was the least yield, its components and quality affecting factor, but environmental conditions (research year) – the most affecting factor. The effect of cultivar and sowing date was mostly substantial, but dependent on evaluated parameter.

Key words: yield; kernel number and weight per spike; 1,000 kernel weigh; protein, gluten, and starch content.

INTRODUCTION

Wheat (*Triticum* L.) together with maize (*Zea mays* L.) and rice *(Oryza sativa* L.) is between worlds' mega crops critically important for food. In 2014, according to FAOSTAT, 221 mill. ha were sown with wheat in the world, but harvested yield reached close to 730 mill. tonnes of grain. Worlds' average wheat yield per ha is still moderate – 3.3 t ha^{-1}. In Latvia, like in many other countries wheat (*Triticum aestivum* L.) has been the mainly grown cereal for many years. Sown area with wheat occupied 448.2 thous. ha in 2015 (38% from the total sown area), including winter wheat 290.6 thous. ha (43% from the total sown area with cereals). Sown area and harvested yield of winter wheat has increased dramatically in Latvia if compared with the time 10 years ago; in 2006, 152.3 thous. ha were sown with winter wheat and total yield was 461.7 thous. t (1,605.7 thous. t were harvested in 2015). An average yield per ha of winter wheat is also steadily increasing in Latvia, and 5.53 t ha^{-1} was obtained in 2015 (in comparison: 3.03 t ha^{-1} in 2006). The dominant position of wheat is the main reason for plenty of research on different aspects of its production and increase in yield, at the same time looking for economical and environmentally friendly methods.

Yield of any crop is mathematical function of separate yield components such as the number of plants per unit area and productivity of an individual plant. For cereals, mainly the number of spikes per 1 m^2, number and weight of kernels per spike, and 1,000 kernel weight (or one kernel weight) is measured (e.g. Slafer et al., 1996; Metho et al., 1998; Thiry et al., 2002). Some researchers analyzed the number of kernels per 1 m^2 and single kernel weight (e.g. Slafer et al., 1996; Frederick et al., 2001; Peltonen-Sainio et al., 2007). A lot of research is devoted to different factors affecting wheat yield and its components.

Yield potential of winter wheat is increased by breeding impressively (Feil, 1992) and increase is also continuing at present. Usually, researchers reported that the number of grain per 1 m^2 (formed by more spikes per 1 m^2 and more kernels per spike) gives the biggest contribution to higher grain yield if compared with single kernel weight in modern cultivars (Feil, 1992; Slafer et al., 2014). Peltonen-Sainio et al. (2007) researched 78 winter wheat genotypes during 30 years in Finland and found that winter wheat yield increase was promoted by both – an increase of kernel number per 1 m^2 and single kernel weight. As much as cultivar genotype also environmental conditions play an important role affecting formation of wheat yield and its components. Soil tillage system was found as a factor with little or irregular (Seibutis es al., 2009; Jug et al., 2011; Malecka et al., 2015) effect on wheat yield components' formation. Tillage effect in combination with crop rotation or production practices of previous crop (Frederick et al., 2001) was more expressed. Many researchers (Sieling et al., 2005; Feizabadi & Koocheki, 2012; Babulikova, 2014) found beneficial effect of crop rotation, especially when more crops were included in it. Appropriate N-fertilization not only increases the winter wheat yield and values of its forming elements, but can also reduce the effect of other unfavourable factors, e.g. crop rotation (Sieling et al., 2005). Fioreze et al. (2012) reported more tillers per plant and 1 m^2 when adequate level of phosphorus fertilizer was given. The use of suitable sowing rate at an optimal sowing date is very important for winter wheat. Researchers showed the compensation action of yield forming elements when different sowing rates were used at different sowing dates (e.g. Spink et al., 2000). Valerio et al. (2009) demonstrated that sowing rate can depend on cultivar tillering ability. Mostly all results of field experiments showed a strong effect of research year or location that also contributes to plasticity and compensation ability of yield components.

Nowadays, not only yield amount but also yield quality is important. For wheat, the main grain quality indicator is crude protein content and protein quality which could be measured by Zeleny index. Also, wet gluten content and starch content are measured frequently. Achievements of breeding ensure different kinds of wheat cultivars suitable for food, feed, ethanol production or other specific purposes. Genotype of cultivar is the first criterion determining specific grain quality parameters, as well as environmental and management conditions (Geleta et al., 2002; Zecevic et al., 2014), especially N-fertilizer rate and timing (Liniņa & Ruža, 2012) plays an important role.

For high winter wheat yield formation, the number of spikes per unit area is an important yield component (Metho et al., 1998), but it can be reached differently. Growers can use high sowing rates or sow little less seeds per 1 m^2 and allow plants to tiller more. Wheat tillering ability is high and plants depending on genotype and environment are able to produce from 1 to even more than 100 tillers (Šeļepov et al., 2013). Suitable number of tillers per plant or per 1 m^2 depends mostly on environmental conditions. Researchers concluded that wheat main stem is generally more productive if compared with the next level tillers (Metho et al., 1998; Elhani et al., 2007; Xu et al., 2015), and grain protein content varied depending on tiller's level and even on floret position in the spike (Metho et al., 1998). Data is hardly ever reported on average per plant values of wheat yield component and quality indicators depending on productive tillering coefficient.

The aim of this research was to evaluate contribution of plants with different tillering coefficient in winter wheat yield formation, and to evaluate yield components forming spike productivity, and grain quality, depending on tillering coefficient, cultivar, sowing date and rate, and conditions of research year.

MATERIALS AND METHODS

Field experiments were carried out at the Study and Research farm 'Peterlauki' of Latvia University of Agriculture (56° 30.658′ N and 23° 41.580′ E) during three seasons (2004–2005, 2005–2006 and 2006–2007). Field trials consisted of four target sowing dates with a 10-day interval from the end of August to the end of September (30 August ± 2 days (1 T); 10 September ± 2 days (2 T); 19 September ± 2 days (3 T) and 29 September ± 2 days (4 T)). Three bread winter wheat (*T. aestivum* L.) cultivars 'Cubus', 'Tarso' and 'Zentos' (originated from Germany) were sown using three sowing rates (300, 400 and 500 germinable seeds per 1 m^2). Field trial was arranged in a three-factorial split-plot design in four replications. Plot size was 25 m^2. Soil at the site was *Endocalcaric Abruptic Luvisol* (World Reference Base, 2014), silt loam; pH KCl = 6.9; available for plants content of P_2O_5 = 247 mg kg^{-1} soil; K_2O = 328 mg kg^{-1} soil, and organic matter content 1.4%.

Winter wheat was sown in bare fallow, but during previous year spring barley (*Hordeum vulgare* L.) was grown in the field. Conventional tillage system, which included mould board ploughing approximately one month before sowing and harrowing directly before sowing, was used. Plots were fertilized with 60 kg P_2O_5 ha^{-1} and 90 kg K_2O ha^{-1} before sowing. Split N-fertilizing (NH_4NO_3; 34% N) was used next spring: 150 kg ha^{-1} in total (N 90 kg ha^{-1} at the renewal of vegetation period and N 60 kg ha^{-1} at the GS 30–32). Certified treated seed was used and sowing depth was 3–4 cm. Plots were maintained free from weeds, pests and diseases using pesticides, and growth regulators were used in order to avoid lodging. Overall, crop management was performed according to the recommendations for the area.

Yield was accounted at the GS 90–92 harvesting and weighing each plot separately. Yield was recalculated in t ha^{-1} at 14% moisture and 100% purity. Winter wheat achieved GS 90–92 in all plots simultaneously (development differences depending on sowing time were observed in spring, but they equalized till milk ripeness stage), and harvesting of all plots was done on the same date (16 August 2005, 04 August 2006 and 02 August 2007).

Before harvesting, sample sheets were taken from 0.25 m^2 in each plot to detect productive tillering coefficient (later on: tillering coefficient – TC) for every plant. Plants were sorted according to the TC, and those with the same number of tillers per plant from the same treatment were joined together. The number of spikes was counted, and then grain was threshed by hand, cleaned, weighted and counted by grain counter Contador (Pfeuffer). Calculations were made as follows: the grain number per spike, grain weight per spike (g), proportion of stems from plants with the same TC per treatment (%), proportion of grain mass from plants with the same TC per treatment (%). Thousand grain weight was detected from the yield and 500 grains were counted twice (LVS EN ISO 520).

Grain quality was measured using Infratec™ 1241 Grain Analyzer (FOSS). It is a whole grain analyser for testing multiple parameters by use of near-infrared transmittance technology. Crude protein, wet gluten and starch content, and Zeleny index was detected. Measurements were done in cases when enough grain was obtained from plants with specific tillering coefficient per treatment.

Analysis of variance was used to evaluate impact of factors to investigation traits.

Pairwise comparisons among factors' levels have been done with Bonferroni test. The factor and differences between factors level were considered statistically significant when $p < 0.05$. Data processing was done using SPSS 15.

Meteorological conditions during three research years greatly differed. During the autumn vegetation period average air temperatures in September and October were slightly above the long-term average (11.7 °C and 6.8 °C respectively) in the region in 2004, but vegetation ended (average day-night temperature for the 5 succeeding days below 5 °C) in early November. Similar average air temperature was observed also in September and October 2005, but the beginning of November was very warm; despite this, vegetation ended in the middle of the 2nd ten-day period of November. Both winters were comparatively stable and did not cause serious wintering problems. In 2006, on the contrary, average air temperatures in September and October exceeded long-term average by more than 2 °C and together with enough precipitation promoted vigorous tillering and outgrowing of plants sown on earlier sowing dates. Vegetation period continued till the middle of December, and also later, till the middle of January 2007, average air temperature was above 0 °C. Temperatures below 0 °C were observed only in late January, but in February they dropped to -11.1 °C. It was a great stress for plants, especially those sown on earlier sowing dates and overgrown during the long and warm autumn vegetation period. This winter heavily affected yield formation, and enumerable yield for cultivar 'Cubus' sown on the first two sowing dates was not achieved. Vegetation started on 8–10 April 2004, 20–21 April 2006 and 25–26 March 2007. Vegetation periods of subsequent summers also differed. Temperature during the summer vegetation period is not a yield limiting factor for winter wheat in Latvia, but this can be grain quality affecting factor. Below the long-term average observations was average monthly air temperatures in May (-0.4 °C) and June (-1.0 °C) 2005, and in July 2007 (-0.5 °C). The long-term average air temperatures were exceeded in May (+0.8 °C) 2007, in June 2006 (+0.8 °C) and 2007 (+1.2 °C), and in July 2005 (+1.1 °C) and 2006 (+3.3 °C). Long-term average sum of precipitation in period May-July was exceeded in 2005 (121% if compared with the long-term average observations) and in 2007 (155%). Distribution of precipitation was comparatively even. In contrast, the summer 2006 was dry securing 77% from long-term average sum of precipitation in May, 50% – in June and 57% – in July. Overall, a severe winter affected winter wheat yield and its components formation in the season of 2006–2007, but a hot and dry summer – in the season of 2005–2006.

RESULTS AND DISCUSSION

Winter wheat yield and effect of plants with different TC in its formation

Average winter wheat yield was high (6.67–9.08 t ha^{-1}; Table 1) and was affected substantially ($p < 0.05$) by all the investigated factors except sowing rate (Table 1). Yield and effect of its determining factors were analysed in detail in previous paper (Ruza & Kreita, 2008).

Table 1. Grain yield of winter wheat depending on investigated factors, and contribution of plants with different tillering coefficient in its composition

Investigated factors	Yield, t ha^{-1}	Contribution of plants with different tillering coefficient in yield composition, %					
		1	2	3	4	5	6
	Cultivar (for yield: $p < 0.001$)			(for yield distribution: $p > 0.05$)			
Cubus	6.67^{a}	18^{A}	17^{AB}	19^{A}	14^{AB}	11^{B}	21^{A}
Tarso	8.96^{b}	9^{A}	16^{AB}	22^{BD}	18^{BDE}	23^{CD}	12^{AE}
Zentos	8.86^{b}	12^{A}	15^{AB}	20^{BC}	19^{BC}	22^{C}	13^{A}
Sowing time (for yield: $p < 0.001$)			(for yield distribution: $p > 0.05$)				
1 T	7.16^{a}	10^{A}	12^{A}	16^{AB}	16^{AB}	23^{B}	23^{B}
2 T	7.63^{a}	11^{A}	13^{AB}	19^{B}	18^{AB}	20^{B}	19^{B}
3 T	8.67^{b}	14^{ACD}	19^{BD}	23^{B}	17^{BC}	17^{BC}	10^{AC}
4 T	9.05^{b}	17^{A}	19^{A}	23^{A}	17^{A}	16^{A}	8^{B}
Sowing rate (for yield: $p = 0.557$)			(for yield distribution: $p > 0.05$)				
300	8.04	11^{A}	13^{AC}	20^{B}	18^{BC}	20^{B}	18^{BC}
400	8.15	13^{A}	16^{AC}	21^{BC}	18^{AC}	19^{AC}	14^{A}
500	8.29	15	18	20	16	17	13
Research year (for yield: $p < 0.001$)			(for yield distribution: $p > 0.05$)				
2005	9.08a	15^{A}	15^{A}	20^{A}	17^{A}	30^{B}	3^{C}
2006	7.94b	10^{A}	15^{AC}	21^{BC}	19^{BCD}	14^{AD}	21^{BC}
2007	7.37b	15^{AC}	17^{AC}	20^{A}	16^{AC}	12^{BC}	21^{A}
		average yield distribution depending on TC: $p < 0.001$					
On average per all factors	**8.16**	**13**	**16**	**20**	**17**	**19**	**15**

$^{AB...E}$ – data mentioned in the same row with different letters significantly differ ($p < 0.01$); ^{abc} – yield data mentioned with different letters significantly differ within the borders of investigated factor (in column).

Plants with TC '1' to '6' were detected in sample sheets every year. Such a good tillering was ensured by comparatively lower plant densities (field germination and wintering lowered the number of plants m^{-2}), good autumn weather conditions, especially for wheat sown at early sowing dates (1 T and 2 T and even 3 T) or suitable tillering conditions in spring (wheat sown on later sowing dates: 3 T and 4 T). Spink et al. (2000) in the UK reported the maximum number of tillers per plant at sowing density 320 seed m^{-2} 4.9, 5.6 and 7.1 depending on a research year. In our case, TC '6' was not achieved in 29% of all observations, but TC '5' in ~2% of observations. All these cases were mainly reported in 2005.

Average contribution of plants with different TC in yield formation was not affected substantially by any of researched factors (Table 1). The most average contribution was given by plants with TC '3' (20%, Table 1), one percentage point less – by those with TC '5' (19%). The least average contribution (13%) was given by plants which did not tiller at all (TC '1') and had only the main stem. Plants with TC '2', '4' and '6' contributed in the yield formation similarly (15–17%). Results correspond to the average proportion of productive tillers given by plants with different TC – the most number of tillers was given by plants with TC '3' (~20%), but the least – by those which did not tiller at all (on average 13%).

Looking on average per investigated factors' contribution of plants with different TC in the yield formation, numerical differences were found, e.g., plants with the TC '6' contributed only 3% in average yield of 2005, and 8% on average for yield obtained when wheat was sown in late September (4 T). Comparatively high was contribution of plants with the TC '4' and '5' in the yield formation (on average 17 and 19% respectively, Table 1), and it gave evidence on high productive tillering ability of winter wheat, thus compensating the shortage of plants in wheat stand. This is illustrated also by lack of sowing rate's impact on yield formation in this particular research ($p = 0.557$; Table 1). Researchers have expressed contrary views about the beneficial effect of tillering on wheat yield. E.g., Donald (1967) imagined the ideal wheat ideotype as a single stem plant with large ear. Elhani et al. (2007) investigating durum wheat (*T. turgidum* var. *durum*) in Spain, found no evidence for either a positive or negative effect of maximum tiller number on grain yield. The environment mainly affected suitable number of tillers. Protič et al. (2009) demonstrated positive effect of TC increase on wheat yield. Whaley et al. (2000) showed that grain yield was maintained with large reduction in plant density due to tillering. Summarizing different views, Šeļepov et al. (2013) wrote that the most yielding are cultivars characterizing with moderate tillering ability (4–5 productive tillers per plant).

Yield components characterising spike productivity

Average grain number and weight per spike were affected substantially by plants' TC (Table 2). Still, these differences were small and irregular. Spike productivity (the number of grain as well as grain weight) of plants which did not tiller at all TC = 1 (Table 2) was the smallest. This is a case, when plants have only the main stem. Similar phenomenon, when plants with TC '1' were less productive, was mostly observed depending on researched factors – on the cultivar (Table 3), sowing rate (Table 4), sowing timing (except 4 T; Table 5), and year (Table 6). A lot of research is devoted to the differences in productivity of main stem and tillers showing main stems as more productive (in terms of grain number and weight per spike) if compared with tillers (Metho et al., 1998; Elhani et al., 2007; Xu et al., 2015). Our previous empirical observations make us think that tillers formed in autumn can be of the same productivity as the main stem (Ruža, 1995). This research showed that average spike productivity of plants with TC '3' to '6' can be at least of the same value or even higher if compared with plants with TC '1' and '2'.

Table 2. Average values of wheat yield components and grain quality parameters for plants with different tillering coefficient

Parameters	Average per plants with different tillering coefficient						*p*-value
	1	2	3	4	5	6	
Grain number per spike	33.5	34.4	34.9	34.7	34.8	34.9	0.004
Grain weight per spike, g	1.45	1.50	1.52	1.51	1.52	1.49	0.006
1,000 grain weight, g	42.98	43.28	43.31	43.14	43.30	42.38	0.242
Grain crude protein content, %	13.5	13.4	13.3	13.3	13.4	13.4	0.870
Grain gluten content, %	25.4	25.2	24.6	24.8	25.0	25.8	0.881
Zeleny index	54	54	54	54	54	52	0.433
Grain starch content, %	65.5	65.7	65.8	65.8	65.7	65.8	0.280

Table 3. Cultivar means of yield components and grain quality parameters depending on wheat tillering coefficient

Cultivar	Average per plants with different tillering coefficient						Average per cultivar
	1	2	3	4	5	6	
	Grain number per spike						$p < 0.001$
Cubus	36.2^{a}	37.8^{a}	38.0^{a}	38.0^{a}	38.4^{a}	37.1^{a}	37.6
Tarso	31.9^{b}	32.3^{b}	32.7^{b}	32.9^{b}	33.0^{b}	33.5^{b}	32.7
Zentos	32.5^{b}	33.2^{b}	33.8^{b}	33.2^{b}	33.3^{b}	32.8^{b}	33.1
	Grain weight per spike, g						$p < 0.001$
Cubus	1.58^{a}	1.66^{a}	1.67^{a}	1.66^{a}	1.68^{a}	1.59^{a}	1.64
Tarso	1.26^{b}	1.29^{b}	1.31^{b}	1.31^{b}	1.32^{b}	1.29^{b}	1.30
Zentos	1.52^{a}	1.55^{c}	1.58^{c}	1.55^{c}	1.56^{c}	1.49^{c}	1.54
	1,000 grain weight, g						$p < 0.001$
Cubus	43.33^{a}	43.71^{a}	43.75^{a}	43.43^{a}	43.53^{a}	42.66^{a}	43.40
Tarso	39.20^{b}	39.67^{b}	39.80^{b}	39.66^{b}	39.79^{b}	38.20^{b}	39.39
Zentos	46.40^{c}	46.46^{c}	46.39^{c}	46.34^{c}	46.57^{c}	45.33^{c}	46.25
	Grain crude protein content, %						$p = 0.051$
Cubus	13.3	13.2	13.2	13.1	13.4	13.5	13.3
Tarso	13.4	13.4	13.4	13.4	13.4	13.2	13.4
Zentos	13.6	13.4	13.3	13.4	13.4	13.6	13.5
	Grain gluten content, %						$p < 0.001$
Cubus	24.4^{a}	24.3	23.9	24.1	25.1	25.5^{ac}	24.6
Tarso	25.4^{ac}	26.0	24.7	24.8	24.7	25.0^{a}	25.1
Zentos	26.4^{bc}	25.2	25.2	25.4	25.2	26.9^{bc}	25.7
	Zeleny index						$p < 0.001$
Cubus	54^{ac}	53	52^{a}	52^{a}	53	52^{ac}	53
Tarso	53^{a}	54	55^{b}	55^{ac}	55	50^{a}	54
Zentos	56^{bc}	55	55^{b}	56^{bc}	55	54^{bc}	55
	Grain starch content, %						$p < 0.001$
Cubus	66.1^{a}	66.2^{a}	66.1^{a}	66.2^{a}	65.7^{a}	66.8	66.2
Tarso	64.4^{b}	64.6^{b}	65.0^{b}	64.8^{b}	64.9^{b}	64.6	64.7
Zentos	65.7^{a}	66.1^{a}	66.3^{a}	66.3^{a}	66.3^{a}	65.7	66.0

Means of parameters in particular TC group mentioned with different letters in superscript are significantly different.

Table 4. Sowing date means of yield components and grain quality parameters depending on wheat tillering coefficient

Sowing date	Average per plants with different tillering coefficient						Average per sowing date
	1	2	3	4	5	6	
	Grain number per spike						$p < 0.001$
1 T	35.3^{a}	36.0^{a}	37.2^{a}	36.8^{a}	37.3^{a}	36.9^{a}	36.6
2 T	34.4^{ac}	35.7^{a}	35.7^{a}	35.6^{ac}	36.1^{a}	35.5^{a}	35.5
3 T	32.5^{bc}	33.3^{b}	33.6^{b}	33.9^{bc}	33.6^{b}	33.3^{b}	33.4
4 T	32.0^{b}	32.8^{b}	32.9^{b}	32.3^{c}	32.0b	31.8^{b}	32.3
	Grain weight per spike, g						$p < 0.001$
1 T	1.55^{a}	1.60^{a}	1.65^{a}	1.64^{a}	1.66^{a}	1.61^{a}	1.62
2 T	1.51^{a}	1.57^{a}	1.58^{a}	1.57^{a}	1.59^{a}	1.51^{a}	1.56
3 T	1.40^{b}	1.45^{b}	1.46^{b}	1.46^{b}	1.45^{b}	1.40^{b}	1.44
4 T	1.36^{b}	1.38^{b}	1.39^{b}	1.36^{b}	1.34^{c}	1.29^{c}	1.35
	1,000 grain weight, g						$p < 0.001$
1 T	43.29^{a}	44.08^{a}	43.83^{a}	43.93^{a}	44.20^{a}	43.24^{a}	43.76
2 T	43.60^{a}	43.60^{a}	43.94^{a}	43.69^{a}	43.79^{a}	42.19^{ac}	43.47
3 T	42.90^{ac}	43.25^{a}	43.21^{ac}	42.99^{ac}	43.19^{a}	42.04^{ac}	42.93
4 T	42.11^{bc}	42.19^{b}	42.27^{bc}	41.96^{bc}	41.89^{b}	40.68^{bc}	41.85
	Grain crude protein content, %						$p < 0.001$
1 T	13.9^{a}	13.7^{ab}	13.7^{a}	13.8^{a}	13.8^{a}	13.7	13.8
2 T	13.7^{a}	13.8^{a}	13.6^{ac}	13.6^{ac}	13.6^{a}	13.6	13.7
3 T	13.4^{ac}	13.2^{b}	13.1^{bc}	13.2^{bc}	13.3^{ac}	13.3	13.2
4 T	12.9^{bc}	12.8^{c}	12.7^{b}	12.7^{b}	12.7^{bc}	13.1	12.8
	Grain gluten content, %						$p < 0.001$
1 T	26.7^{a}	25.4	25.9^{a}	26.1^{a}	26.0^{a}	26.1	26.0
2 T	25.9^{a}	26.1	25.6^{ac}	25.8^{a}	26.2^{a}	26.3	26.0
3 T	25.1^{ac}	25.7	24.2^{bc}	24.4^{ac}	24.6^{ac}	25.4	24.9
4 T	23.8^{bc}	23.3	22.7^{b}	22.9^{bc}	23.1^{bc}	25.0	23.5
	Zeleny index						$p < 0.001$
1 T	56^{a}	56^{a}	56^{a}	57^{a}	58^{a}	54^{a}	56
2 T	56^{a}	57^{a}	57^{a}	56^{a}	57^{a}	53^{ac}	56
3 T	54^{a}	54^{a}	53^{ac}	55^{a}	54^{a}	50^{ad}	53
4 T	50^{b}	50^{b}	50^{bc}	49^{b}	48^{b}	49^{bcd}	49
	Grain starch content, %						$p < 0.001$
1 T	64.8^{a}	65.2^{a}	65.2^{a}	65.2^{a}	65.1^{a}	65.1	65.1
2 T	65.2^{a}	65.0^{a}	65.4^{ac}	65.4^{a}	65.3^{a}	65.0	65.2
3 T	65.6^{ac}	66.0^{b}	66.0^{bc}	66.0^{ac}	65.8^{ac}	67.2	66.1
4 T	66.2^{bc}	66.3^{b}	66.6^{b}	66.4^{bc}	66.5^{bc}	65.8	66.3

Means of parameters in particular TC group mentioned with different letters in superscript are significantly different.

Grain number per spike for plants with the same TC depending on cultivar was different in all the cases ($p < 0.05$). The most number of grain per spike was noted for cultivar 'Cubus' (36.2 for plants with TC '1' to 38.4 for plants with TC '5') (Table 3). Differences between max. and min. number of grains per spike depending on tillering coefficient were 1.3, 1.6 and 2.3 grains for cultivars 'Zentos', 'Tarso' and 'Cubus' respectively. Gradual and even increase depending on TC increase from '1' to '6' was established only for cultivar 'Tarso'. Also, the biggest average grain weight per spike ($p < 0.001$) was noted for cultivar 'Cubus' (1.64 g) and significant cultivar impact on this parameter was observed for plants in groups of all evaluated TC. The biggest grain weight per spike was established for plants with TC '2' to '5' for 'Cubus', with TC '3' to '5' for 'Tarso' and with TC '3' – for 'Zentos' (Table 3). Sowing time effect was substantial on average grain number per spike ($p < 0.001$; Table 4). Later sowing caused regular reduction of grain per spike and grain weight per spike on average and in all cases in groups with different TC.

Sowing rate increase caused small decrease of grain number and weight per spike, but changes were not linear: sometimes the smallest values were established when sowing rate 400 germinable seeds m^{-2} were sown (the number of grain per spike when TC was '2'and '6'; grain weight per spike when TC was '1', '2' and '6'; Table 5).

Table 5. Sowing rate means of yield components and grain quality parameters depending on wheat tillering coefficient

Sowing rate	Average per plants with different tillering coefficient						Average per sowing rate
	1	2	3	4	5	6	
	Grain number per spike						$p = 0.001$
300	34.3	35.3	35.3	35.0	35.4	34.7	35.0
400	33.2	33.9	34.9	34.9	34.8	34.4	34.3
500	33.1	34.2	34.3	34.1	34.2	34.6	34.1
	Grain weight per spike, g						$p = 0.01$
300	1.50	1.54	1.54	1.52	1.54	1.48	1.52
400	1.43	1.47	1.52	1.51	1.52	1.45	1.48
500	1.44	1.49	1.50	1.49	1.48	1.47	1.48
	1,000 grain weight, g						$p = 0.736$
300	43.21	43.27	43.38	42.92	43.46	42.49	43.12
400	42.89	43.20	43.24	43.34	43.18	42.02	42.98
500	42.83	43.36	43.32	43.18	43.23	41.90	42.97
	Grain crude protein content, %						$p = 772$
300	13.5	13.3	13.4	13.3	13.4	13.4	13.4
400	13.4	13.4	13.3	13.3	13.3	13.5	13.4
500	13.4	13.3	13.2	13.3	13.3	13.5	13.3
	Grain gluten content, %						$p = 0.685$
300	25.7	25.1	24.8	24.7	25.2	25.8	25.2
400	25.3	25.6	24.7	24.8	24.9	25.8	25.2
500	25.1	24.8	24.3	24.8	25.0	25.6	24.9
	Zeleny index						$p = 0.013$
300	54	53	55	55	56	52	54
400	55	54	55	54	54	52	54
500	54	54	53	54	53	52	53
	Grain starch content, %						$p = 0.402$
300	65.3	65.5	65.7	65.7	65.6	65.4	65.1
400	65.5	65.6	65.8	65.8	65.7	65.3	65.6
500	65.6	65.7	65.8	65.7	65.7	66.4	65.8

Spink et al. (2000) and Whaley et al. (2000) noted significant reduction of number of grain per spike with plant density increase, but in their trials wide range of seed rates or plant densities were studied (20 to 640 seeds m^{-2} and 19 to 338 plants m^{-2} respectively).

The effect of year conditions on grain number and weight per spike was substantial ($p \leq 0.01$; Table 6) and similar differences were observed in all the groups depending on TC. The biggest values were established in 2007 when wintering conditions reduced the plant number per 1 m^2 considerably, but the following spring and summer favoured an increase in spike productivity. The smallest spike productivity was noted in 2006 when lack of precipitation was observed together with overly warm temperatures if compared with long-term average data. McMaster et al. (1994) showed that irrigation increased grain number per spike and grain weight per plant in the US Great Plains where water is commonly wheat yield limiting factor.

Table 6. Year means of yield components and grain quality parameters depending on wheat tillering coefficient

Research year	Average per plants with different tillering coefficient						Average per year
	1	2	3	4	5	6	
	Grain number per spike						$p < 0.001$
2005	33.8^a	34.0^a	34.4^a	34.1^a	34.8^a	40.7^a	35.3
2006	30.1^b	31.7^b	31.9^b	31.9^b	32.1^b	31.7^b	31.6
2007	36.1^c	37.7^c	38.3^c	38.0^c	37.6^c	36.4^c	37.4
	Grain weight per spike, g						$p < 0.001$
2005	1.54^a	1.56^a	1.58^a	1.55^a	1.59^a	1.88^a	1.62
2006	1.16^b	1.21^b	1.22^b	1.22^b	1.24^b	1.20^b	1.21
2007	1.67^c	1.73^c	1.76^c	1.75^c	1.73^c	1.66^c	1.72
	1,000 grain weight, g						$p < 0.001$
2005	45.42^a	45.66^a	45.55^a	45.37^a	45.48^a	46.22^a	45.61
2006	37.62^b	38.30^b	38.39^b	38.09^b	38.56^b	38.12^b	38.18
2007	45.89^a	45.88^a	46.00^a	45.97^a	45.97^a	45.55^a	45.88
	Grain crude protein content, %						$p < 0.001$
2005	12.9^a	12.9^a	12.9^a	13.0^a	13.2^a	13.0	13.0
2006	13.9^b	13.8^b	13.6^{bc}	13.6^{bc}	13.7^b	13.6	13.7
2007	13.3^a	13.3^a	13.3^{ac}	13.3^{ac}	13.2^a	13.3	13.3
	Grain gluten content, %						$p < 0.001$
2005	21.5^a	22.9^a	21.9^a	22.1^a	22.7^a	21.6^a	22.1
2006	27.6^b	26.7^{bc}	26.7^b	26.7^b	26.7^b	26.7^b	26.9
2007	25.2^c	25.2^{ac}	25.1^c	25.3^c	25.3^c	25.2^c	25.2
	Zeleny index						$p < 0.001$
2005	60^a	60^a	60^a	60^a	63^a	61^a	61
2006	56^b	55^b	54^b	54^b	53^b	54^b	54
2007	49^c	49^c	49^c	49^c	48^c	49^c	49
	Grain starch content, %						$p < 0.001$
2005	66.9^a	66.8^a	66.8^a	66.7^a	66.6^a	66.8	66.8
2006	64.9^b	65.1^b	65.1^b	65.4^b	65.2^b	66.1	65.3
2007	65.2^b	65.4^b	65.4^b	65.3^b	65.3^b	65.2	65.3

Means of parameters in particular TC group mentioned with different letters in superscript are significantly different.

Changes of spike productivity depending on TC within specific year were not so regular. The largest grain number and weight per spike in 2005 were observed when TC was ’5’ and ’6’, in 2006 – the grain number per spike when TC was ’3’ and ’4’, but weight per spike – when TC was '5', but in 2007 the most values of detected parameters were established when TC was '3'.

It was shown by many authors (e.g. Zwer et al., 1995; Thiry et al., 2002; Abdoli & Saeidi, 2012; Li et al., 2016) that 1,000 grain weight (or one grain weight) is a strongly cultivar-dependent and comparatively stable characteristic or yield component.

TC of plant did not affect significantly average values of 1,000 grain weight (TGW) ($p = 0.242$; Table 2). Used cultivar affected TGW on average and when plant groups with different TC were evaluated ($p < 0.001$; Table 3). The difference observed between the lowest and highest TGW values depending on TC within the same cultivar was 1.09 g for 'Cubus', 1.60 g for 'Tarso' and 1.24 g for 'Zentos'. The lowest TGW for all the cultivars was observed for plants with TC '6', but the highest – for plants with TC '3' for cultivars 'Cubus' and 'Tarso', and with TC '5' – for cultivar 'Zentos'. It has to be remarked that difference between 1,000 grain weight (except the smallest and biggest values) of plants with two different TC was small.

Sowing rate effect was not signifficant on average TGW ($p = 736$; Table 5). Li et al. (2016) investigating four very contrastive plant densities (75 to 525 plants m^{-2}) found significant TGW differences within the investigated plant densities which depended on cultivar (i.e., significant cultivar × plant density interaction effect on TGW was observed). On the contrary, Zecevic et al. (2014) investigating five cultivars sown with two sowing rates (500 and 600 seed m^{-2}) three years found TGW increase with sowing rate increase in all genotypes and investigated years.

Later sowing date caused gradual decrease of average values of TGW ($p < 0.001$; Table 4). Gradual decrease of average TGW was observed also for plants with the same TC sown in different sowing times (only two exceptions were observed: if TC was '1' and '3' the highest TGW was observed if wheat was sown on 2 T). This agrees with results of Spink et al. (2000) who found well expressed TGW reduction by later sowing date (three dates were used) in one of trial years, in other one – decrease was not so clear between the 2nd and 3rd sowing dates, and in the third research year later sowing promoted even higher TGW.

Conditions of research year caused substantial ($p < 0.001$; Table 6) TGW differences. Similar average TGW values were observed for 2005 and 2007 (Table 6), but insufficient amount of precipitation, especially during the grain fill and TGW formation reduced TGW in 2006 by more than 7 g if compared with two other research years. Our results agree with findings of Abdoli & Saeidi (2012) who wrote that post-anthesis water stress decreased TGW. The smallest difference between the TGW max. and min. value depending on TC within the same year was observed in 2007 (0.45 g between TGW of plants with TC '3' and TC '6'), but the biggest – in 2006 (0.94 g between TGW of plants with TC '5' and TC '1') (Table 6).

Although TGW is genetically stable yield component, almost all researchers showed substantial environmental or year effect on TGW in field trials (e.g., Spink et al., 2000; Frederick et al., 2001; Elhani et al., 2007; Jug et al., 2011; Zecevic et al., 2014).

Grain quality

Wheat TC did not affect average values of any of measured quality indicators ($p > 0.05$; Table 2): crude protein (CP), wet gluten (WG) and starch content, and Zeleny index.

As all three cultivars used in trial are bred for bread making purposes, differences in their average crude protein (CP) content were not substantial ($p = 0.051$; Table 3); difference between max. and min. values was 0.2%. CP content in grain obtained from plants in groups with different TC also was not substantially different ($p > 0.05$) depending on cultivar. Similarly, sowing rate did not affect substantially average CP content ($p = 0.772$) and CP content in different TC groups (Table 5). Metho et al. (1998) reported small, but not significant differences in CP content between the main stem and tillers whereas Geleta et al. (2002) established CP increase with the sowing rate decrease. At the same time researchers concluded that the quality traits are greatly influenced by the environment and in less extent by the sowing rates.

Sowing date and trial year showed mathematically substantial effect ($p < 0.001$) on average CP content. CP content differed essentially also in every TC group depending on the sowing date (Table 4) and trial year (Table 6). The sowing date delay to 3 T caused CP decrease for 0.5–0.6 percentage points, but till 4 T – even for 0.9–1.1 percentage points in most cases. The highest average CP content was observed in 2006, which was dry and warm during the grain fill and protein synthesis.

The cultivar influence on average WG content was substantial ($p < 0.001$) that agrees with many other results (e.g. Linina & Ruza, 2012; Zecevic et al., 2014); difference between max. and min. values was 1.1 percentage point. Analysing average WG values of cultivars within the specific TC groups, influence of cultivar on WG content was not consistent: it was substantial only in groups with TC '1' ($p = 0.007$) and TC '6 ' ($p = 0.02$). Sowing rate did not influence WG content essentially ($p > 0.05$). Zecevic et al. (2014) investigating two comparatively high sowing rates (500 and 650 seed m^{-2}) in Serbia found that higher sowing rate is beneficial for increase of WG content. Substantial sowing date influence on average WG content was established. Similar were values of WG content if wheat was sown at 1 T and 2 T, but obviously lower – when it was sown at 3 T and 4 T. This regularity was observed in all groups with the specific TC. Similarly to CP also average WG content was affected by trial year substantially confirming the verity that the environment affects grain quality greatly.

Although all values of Zeleny index correspond to demands for grain of good baking quality still the cultivar, sowing date and research year affected them substantially on average and within the groups with specific TC. Sowing rate affected Zeleny index on average ($p = 0.013$; Table 5), but substantial effect of sowing rate in any of groups with specific TC was not observed ($p > 0.05$). If sowing rate 500 seeds per m^{-2} was used, the least average Zeleny index (53; Table 5) was observed and it is contrary to Zecevic et al. (2014) who concluded that with a sowing rate increase also Zeleny index increases. Similarly to CP and WG, also Zeleny index decreased substantially if wheat was sown at 3 T and 4 T. The most expressed was influence of research year similarly to many other research results: the max. value was established in 2005 (61), but the min. value – in 2007 (49) (Table 6).

Starch is a grain quality indicator that is not so important for bread baking, but is more important if wheat is used as feed for livestock or for ethanol production. In our trial, an average starch content (65.7%) was not extremely high, but it was characteristic for bread wheat. This indicator was substantially affected by cultivar, sowing date and research year on average and in every group with different TC, and it was not affected by sowing rate ($p = 0.402$; Table 5). Starch content values were mostly inversely related to CP values. It is a well-known fact that CP and starch content in most cases correlates negatively.

CONCLUSIONS

Plants with tillering coefficient (TC) '1' to '6' were detected during all three research years, but the biggest average contribution in yield formation gave plants with TC '3'. Depending on investigated factor and environment, also any other TC group can give similar contribution.

TC showed substantial effect on two yield-forming components: the number and weight of grain per spike. Though differences were inconsistent, and further investigations are needed. Clear regularity was found that both spike productivity indicators were higher in groups with TC ≥ 2 if compared with plants that did not tiller at all. Thousand grain weight and grain quality indicators (crude protein, wet gluten and starch content, and Zeleny index) were not affected by TC. Thus, tillering is beneficial for winter wheat yield formation and is important mechanism in compensation of yield components.

Sowing rate mostly did not affect investigated yield forming elements and quality indicators. Contrariwise, winter wheat cultivar used and sowing time mostly affected investigated parameters substantially. If winter wheat was sown on 20 September and later (3 T and 4 T) the yield increased, but the quality of grain mostly decreased (except starch content) insignificantly. Conditions of research year substantially affected all investigated yield components and quality indicators, thus showing that the environmental effect is more critical if compared with the effect of sowing rate and in some cases even if compared with the effect of cultivar.

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