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Variability of the thousand-seed weight in bread wheat (*Triticum aestivum* L.)

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Abstract

The thousand-seed weight (TSW) is one of the traits which is related to yield and milling quality of wheat. The aim of this work was to study the variability of the thousand-seed weight of bread wheat varieties grown under different environmental conditions. Fifty wheat varieties in a field experiment designed as a randomized block system were used for this study in three replications on the field in Kraljevo, Serbia during two vegetation seasons (2015-2017). The seeds were sown at 0.10 m distance in 1.0 m long rows spaced apart 0.2 m. Sixty plants at the full maturity stage (20 plants replication-1) were harvested and used for analyzing the thousand-seed weight. The analysis of variance was performed by MSTAT C (5.0 version). Similarities among wheat varieties were analyzed by using the hierarchical method of the Euclidean distance. The results have shown significant differences in the thousand-seed weight among varieties in both years. On average, in the first vegetation season the lowest thousand-seed weight (39.14 g) was recorded in the Lepenica variety, while the highest thousand-seed weight (54.66 g) was recorded in the Zadruga variety. In the second vegetation season, the thousand-seed weight varied from the lowest in NS Rana 2 (34.57 g) to the highest in Šumadinka (50.33 g). The similarity was illustrated on a dendogram containing four clusters in the first year and six clusters of varieties in the second year. The prominent cluster contained different numbers and compositions of varieties with the highest degree of similarity. The differences in average of the thousand-seed weight were determined by the genetic, environmental factor and by genotype/environment interaction.

Key words: wheat, variety, thousand-seed weight, similarity, environment.

Introduction

The creation of high yielding wheat varieties with good quality is a primary focus in breeding programs. Breeders have a difficult task, given that there is a negative correlation between seed yield and protein content (Acreche and Slafer, 2006) as well as some yield components and quality traits (Groos et al., 2002; Blanco et al., 2012; Matković Stojšin et al., 2018). The increasing seed yield in wheat breeding programs can be achieved through genetic improvements of yield components: the number of seeds per spike, spike number per unit area, thousand seed weight (Knežević et al., 2006; Kondić et al., 2017; Mian et al., 2019; Urošević et al., 2022; Zhang et al., 2013), growth characteristics: seed filling rate and duration, plant height (Yang et al. 2020; Knežević et al., 2020a), and the characteristics of the spikes and seeds, inflorescence, as well as the morphological and physiological characteristics of the stem, leaves, and roots of the plant (Branković et al., 2015; Du et al., 2022; Knežević et al., 2020). The seed yield is a complex trait controlled by numerous genes for yield components, the expression of which is modified by the influence of environmental factors (Ma et al, 2016; Miao et al., 2017; Zhang et al., 2017; Wang et al., 2020).

The thousand-seed weight (TSW) is one of the components which has a significant impact on determination of wheat seed yield (Ferrante et al., 2017), controlled by genes mapped on different chromosomes 1A, 1B, 1D, 2A, 2B, 2D, 3A, 3B, 4D, 5D, 7A, and 7B (Rathan et al., 2022) 2B, 5A, 6A, 7B, 5B, 2D, 7A, and 5D whose expression can be affected by the environment and genotype-environment interactions (Krishnappa et al., 2022). Some of them have been identified in the pleiotropic region, e.g. 2BL for chlorophyll content (Zhu et al., 2016), and for seed protein content on 2A, 2B, chromosomes (Rathan et al., 2022). Genotypes with accumulation of favourable alleles have a significant positive effect on thousand-seed weight (Wang et al., 2012; Cristina et al., 2021).

The thousand seed weight can vary due to the seed size, i.e. seed length, width, and thickness (Abdipour et al., 2016), which is negatively correlated with the seed number in a spike, mainly due to competition for available assimilates (Kumar et al. 2016), which depends on the position of the spikelet in a spike (whether the spikelet is on the basal part, in the middle, or at the top of the spike). Large seeds have favourable effects on seedling vigour and early growth, which enable high and stable yield. By increasing the efficiency of seed filling by assimilate is one possible way to overcome low seed mass, as well as the thousand-seed weight which is one of the most essential components of seed yield (Zečević et al., 2004; Knežević et al., 2018; Wolde et al., 2019). In order to obtain wheat varieties with high seed yield, it is necessary to know the genetic control of the thousand-seed weight as well as other components of yield and quality, their mutual connection, and the effect of environmental factors (Zečević et al., 2005; Wei et al., 2014; Knežević et al., 2020b; Würschum et al., 2018).

The aim of the work was to study the variability of the thousand-seed weight in divergent bread wheat varieties grown under different agro-ecological conditions.

Material and Methods

In this study 50 wheat varieties were included. Selected wheat genotypes were sown in an experiment which was set up as a randomized block design in three replications, on 1 m^2 plots size on the field in Kraljevo, Serbia in two growing seasons (2015/16 and 2016/17). The seeds were sown at 0.10 m distance in 1.0 m long rows spaced apart 0.2 m. Sixty plants at the full maturity stage (20 plants replication-1) were harvested and used for analyzing the thousand-seed weight. The analysis of variance was performed by MSTAT C (5.0 version), and significant differences were estimated by F-test values and tested by value of LSD 0.05 and LSD 0.01. Similarities among wheat varieties were analyzed by using the hierarchical method of the Euclidean distance.

Weather conditions

During the two-year experimental research temperature and precipitation values were recorded. The average temperature was 9.96 °C and the total amount of precipitation was 651mm in the first year which was higher than in the second, 2016/17 growing season when the average temperature was 8.74 °C and the total amount of precipitation was 523 mm, and also higher than the 10 year average temperature of 8.50 °C with 417.8 mm precipitation. In the two months (October-November) the amount of precipitation and average temperature values were similar, having been favourable for seed germination and development of plants. During February-April the amount of precipitation in the first year (250.5 mm) was higher than in the second (174.0 mm), although the distribution of rainfall was more favourable for plant growth in the second year of the experiment (Table 1).

Table 1 Average monthly temperatures and total monthly precipitation in Kraljevo

	Period	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Xm	Total
Temperature °C	2015/16	11.6	7.3	3.3	-0.1	8.8	7.8	14.1	15.5	21.3	9.96	
Temperature °C	2016/17	10.6	6.8	0.0	-4.7	5.2	10.8	11.1	16.8	22.1	8.74	
Temperature °C 2000-2010		11.8	6.4	1.7	-0.1	2.6	5.9	11.6	16.4	20.4	8.50	
Precipitation (mm)	2015/16	56.8	64.0	9.0	86.2	52.7	157.9	39.9	135.9	48.6		651.0
Precipitation (mm)	2016/17	84.1	77.6	9.4	22.0	35.0	57.0	82.0	100.0	56.0		523.1
Precipitation (mm) 2000-2010		61.0	44.3	44.6	30.0	29.9	33.2	52.9	52.6	69.3		417.8

*(*source: Republic Hydrometeorological Service of Serbia)*

Results and Discussion

The thousand-seed weight of the wheat varieties under study varied in the range of 39.14 g (Lepenica) to 54.66 g (Zadruga) in the first vegetation season with an average value of 44.24 g for all 50 varieties, while in the second year the thousand-seed weight varied from 34.57 g (NS Rana 2) to 50.33 g (Šumadinka) with an average value of 42.65 g (Table 2).

On average the highest thousand-seed weight for two growing seasons was in the Gruža variety (50.33 g) and the lowest in the Sasanka variety (36.93 g). On average for all varieties. the thousand-seed weight was higher in the first (44.24 g) than in the second vegetation season (42.65 g) (Table 2).

Table 2 Variability of the thousand seed weight in the bread wheat varieties

	Cultivars	First year	Second year	Average		Cultivars	First year	Second year	Average
1	Evropa 90	42.31	39.10	40.71	26	Jarebica	44.26	50.00	47.13
2	Dejana	43.29	44.63	43.96	27	Fortuna	42.11	40.13	41.12
3	Sila	41.35	42.37	41.86	28	Sasanka	42.02	31.85	36.93
4	Omega	46.60	45.80	46.04	29	Danica	41.45	39.10	40.28
5	Lasta	44.76	45.20	46.20	30	Somborka	43.10	39.93	41.52
6	Milica	44.66	44.60	44.63	31	Kremna	41.38	39.70	40.54
7	Parizanka	41.58	43.60	42.59	32	KG-75	52.23	42.53	47.38
8	Pobeda	47.17	46.00	46.60	33	Šumadinka	42.41	50.33	46.37
9	Dična	43.97	43.87	43.92	34	Levčanka	42.15	39.97	41.06
10	NS Rana 5	47.41	41.17	44.29	35	Oplenka	47.78	43.47	45.63
11	Alfa	41.29	44.47	42.88	36	Gruža	49.08	49.10	49.09
12	Rodna	41.74	38.37	40.06	37	Gružanka	40.99	43.50	42.25
13	Balkan	51.30	37.73	44.52	38	KG-58	45.40	39.40	42.40
14	Rana Niska	41.29	45.07	43.18	39	KG-56	48.30	44.73	46.52
15	Proteinka	45.58	36.47	41.03	40	Orašanka	45.77	48.10	46.94
16	Stepa	41.96	44.70	43.33	41	KG-78	42.56	45.30	43.93
17	NSR-2	41.97	34.57	38.27	42	Ravanica	41.54	44.50	43.02
18	Prima	40.60	39.27	39.94	43	Lepenica	39.14	42.20	40.67
19	Sloga	40.81	39.30	40.06	44	Jasenica	42.59	42.60	42.60
20	Agrounija	46.53	38.80	42.67	45	Zastava	44.02	45.43	44.73
21	Zadruga	54.66	40.47	47.57	46	Kosmajka	42.91	40.73	41.82
22	Tera	43.75	51.27	47.51	47	Šumadija	40.46	41.07	40.77
23	Kompas	47.69	43.23	45.46	48	Morava	46.75	46.97	46.86
24	Tanjugovka	41.06	42.40	41.73	49	KG 56 S	47.58	43.77	45.68
25	Jugoslavija	47.03	42.20	44.62	50	Ljubičevka	45.81	40.27	43.04
	Average						44.24	42.65	43.44
	h^2	94.96							

According to other authors' results, the weight of 1000 seeds varies from 43.2 g to 44.6 g (Varga et al., 2000), from 32.2 g to 35.9 g (Jaćimović et al., 2012), from 30.6 g to 43.9 g (Jocković et al., 2014), from 26.6 g to 51.4 g (Mladenov, 2017), from 28.5 g to 43.3 g (Filipović et al., 2018), from 33.83 g to 48.74 g (Arya et al., 2018), from 26.21 g to 38.88 g (Feng et al., 2018) from 32.40 g to 59 .47 g (Šumaruna et al., 2022) from 30.3 g to 58.6 g (Sewore and Abe, 2024). In the total variation of the mass of 1000 seeds, the largest share of interaction between the genotype and external environment was established (Sime and Tesfaye, 2021).

Heritability in a broader sense as the ratio between genetic and total or phenotype variability for the weight of 1000 seeds in wheat was on average 94.96% and showed a high stability of this trait. Also, high heritability of the weight of 1000 seeds was found in other studies 68.10% (Arya et al., 2017), 68.20% (Arya et al., 2018), 78.92% (Geneti et al., 2022), and 67.60% and 63.22% in two growing seasons (Ahmed et al., 2023), while lower heritability 40.40% was found in the research conducted by Regmi et al. (2021).

The analysis of variance in the first and in the second growing season has shown that there are highly significant differences ($p<0.01$) between the varieties according to the thousand-seed weight in both growing seasons. Differences between vegetation season for the thousand-seed weight in the varieties indicate that there is an influence of environmental factors on the thousand-seed weight. The established significant differences in the average values of the thousand-seed weight indicate genetic divergence of varieties (Table 3 and 4).

Table 3 Analysis of variance for the 1000-seed weight in wheat in the first vegetation 2015/16 season

Source of variance	*df*	*SS*	*MS*	*F*	σ^2	$Lsd_{0.05}$	$Lsd_{0.01}$
Genotypes (G)	49	1629.937	33.264	56.380**	11.481	1,765	2,336
Repetitions (R)	2	1.528	0.764	1.2951			
Error	98	57.819	0.590				
Total	149	1689.284					

Table 4 Analysis of variance for the 1000-seed weight in wheat in the second vegetation 2016/17 season

Source of variance	*df*	*SS*	*MS*	*F*	σ^2	$Lsd_{0.05}$	$Lsd_{0.01}$
Genotypes (G)	49	2203.575	44.971	58.626**	15.502	1.999	2.646
Repetitions (R)	2	0.972	0.486	0.6333			
Error	98	76.145	0.767				
Total	149	2279.720					

Based on the values obtained for the thousand-seed weight, four clusters of mutually similar genotypes were distinguished in the first vegetation season (2015/16). The first cluster contained 25 varieties, second 3 varieties, third 8 varieties, and fourth 14 mutually similar varieties. Among those four clusters, the highest similarity was between third and second fourth cluster. The second cluster of three varieties had the greatest similarity with these two clusters, but at a lower hierarchical level. The first cluster had the lowest degree of similarity with a cluster formed by three mutually similar clusters (second, third, and fourth) (Figure 1).

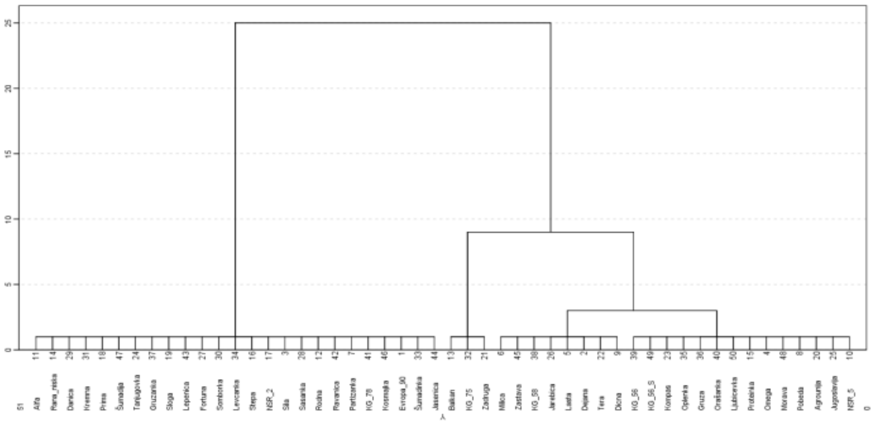

Figure 1. Similarity of wheat genotypes according to the thousand-seed weight in the vegetation 2015/16 season

In the second year (2016/17), five clusters of mutually similar varieties were established. The first cluster contained 13 varieties, second 11 varieties, third 6 varieties, fourth 17, and fifth 3 mutually similar varieties. The formed clusters had a different level of similarity of wheat varieties for the thousand-seed weight. The greatest similarity was between the first and second clusters, followed by a slightly greater distance, the similarity was established between the fourth and fifth clusters of varieties. The third cluster of varieties was similar to the first and second clusters but at a lower hierarchical level. The cluster formed from the first, second, and third had the least similarity at the greatest distance with the cluster formed by the fourth and fifth cluster (Figure 2).

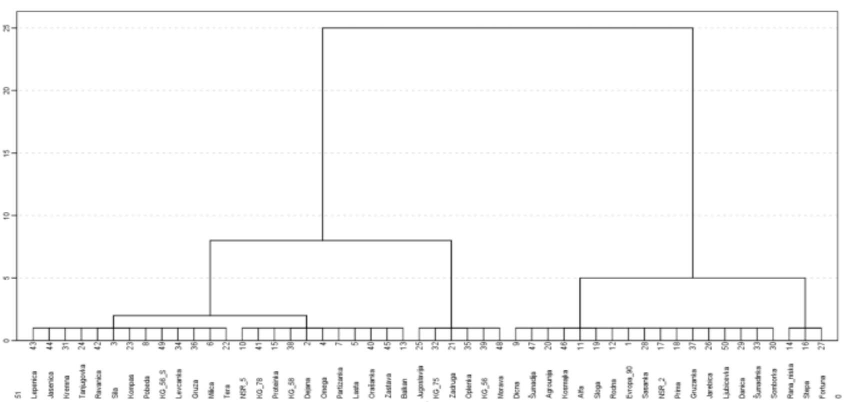

Figure 2. Similarity of wheat genotypes according to the thousand-seed weight in the vegetation 2016/17 season

The thousand-seed weight is a very important indicator of seed quality, which is expressed through seed germination potential, plant growth, and plant characteristics (Shahwani, et al., 2014). This quality is determined by the size of the embryo and reserve substances in the endosperm of the seed, which are a source of food in the process of germination and seedling growth (Bareke et al., 2018). In the production itself, the mass of thousand seeds is used to determine the sowing density and sowing rate, and it can also be an indicator of the quality of other traits, such as the shape and size of the seeds, their uniformity, which depends on the genotype and ecological conditions during vegetation (Heimbach, 2018; Sewore and Abe, 2024). The thousand- seed weight of the same genotype can vary by about 30% or more, depending on the environmental conditions, whereby stressful conditions negatively affect the translocation of photosynthate into seeds. A longer period of high temperatures (heat stress) affects the shortening of the seed filling period, which results in a decrease in the mass of 1000 seeds and the hectolitre mass (Djukić et al., 2019). The greatest contributors to the increase in the thousand-seeds weight and yield include soil moisture. mineral nutrition, and accessibility of mineral elements for absorption, temperature, light, and the process of photosynthesis and reutilization and translocation of organic matter (Devate et al., 2023; Dodig et al., 2008; Rathan et al., 2022). The high thousand-seed weight variability for wheat as well as for any other plant species may be explained by the intensive breeding programs in this crop species.

Conclusion

This study has determined significant differences among wheat varieties according to the thousand-seed weight. The variation of the thousand-seed weight in the same variety in two vegetation seasons indicates a genotype's response to different environmental conditions. The highest value of thousand-seed weight was in the Zadruga variety (54.66 g) and the lowest in Lepenica (39.14 g) in the first vegetation season, while the highest thousand seed weight in the second vegetation season was in Šumadinka (50.33 g) and the lowest in NS Rana 2 (34.57 g). The differences between genotypes were significant and highly significant for the thousand-seed weight. Genetic factors, environmental factors, and genotype/environment interaction had an influence on the manifestation of thousand-seed weight.

For both growing seasons the Gruža variety on average had the highest weight of 1000 seeds (49.09 g) and the Sasanka variety had the lowest weight of 1000 seeds (36.93 g). The similarity between varieties according to the weight of 1000 seeds in the first growing season has been expressed in four clusters, and in the second growing season in five clusters, which are interconnected at different hierarchical levels. It has been found that similar varieties in clusters in the first growing season had greater similarity with other varieties and were grouped in different clusters similar to each other in the second growing season.

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Варијабилност масе хиљаду семена код хлебне пшенице (*Triticum aestivum* L.)

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Сажетак

Маса хиљаду семена је једна од особина која има удео у формирању приноса и квалитета млевења пшенице. Циљ овог рада био је проучавање варијабилности масе хиљаду семена код сорти хлебне пшенице гајених у различитим условима спољашње средине. За проучавање је коришћено 50 сорти пшенице у пољском огледу у Краљеву, Србија који је изведен у рандомизованом блок систему у три понављања и у две вегетационе сезоне (2015-2017). Семе сорти је посејано на растојању од 0,10 m у редове дужине 1,0 m између којих је био размак од 0,2 m. У фази пуне зрелости је пожњевено 60 биљака (20 биљака по понављању) које су коришћене за анализу масе хиљаду семена. Анализа варијансе је извршена помоћу MSTAT C (верзија 5.0). Сличност сорти пшенице је оцењена коришћењем хијерархијске анализе Еуклидске дистанце. Резултати су показали значајне разлике у маси хиљаду семена међу сортама у обе године, на основу вредности F-теста. У просеку, у првој вегетационој сезони најмања маса хиљаду семена је нађена код сорте Лепеница (39,14 g), а највећа код сорте Задруга (54,66 g). У другој вегетационој сезони маса хиљаду семена је варирала од најмање 34,57 g (код НС Рана 2) до највеће 50,33 g (код сорте Шумадинка). Сличност је илустрована на дендограму који је садржао четири кластера у првој години и шест кластера међусобно сличних сорти у другој години. У сваком кластеру је био различит број сорти са највећим степеном сличности. Установљено је да неке сорте које су биле у истом кластеру у првој вегетационој сезони, су биле у истом кластеру и у другој вегетационој сезони, а да су неке сорте из различитих кластера показале сличност у другој вегетационој сезони (тј. груписале су се у исти кластер). Разлике у просечној маси хиљаду семена детерминисане су под утицајем генетичких фактора, фактора средине и интеракције генотип/средина

Кључне ријечи: пшеница, сорта, маса хиљаду семена, сличност, животна средина.

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