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VARIATION OF SPIKE HARVEST INDEX IN WHEAT (*Triticum aestivum* L.)

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Abstract: Spike harvest index (SHI) can be an indicator of partitioning assimilation into seeds vegetative biomass and wheat productivity. The aim of this study is estimation of spike harvest index variation in wheat varieties grown under different environmental conditions. Twenty genetically divergent winter wheat cultivars were included in two years which characterized different weather conditions. On the field experiment in randomized block design in three replications, the seeds of varieties were sown at the distance of 0.10 m in rows of 1.0 m length with the distance of 0.2 m. For analysis of spike harvest index determined in proportion of seed mass spike^{-1}/mass of spike, 60 plants in full maturity stage (20 plants per replication) were used. The results showed differences of spike harvest index among varieties and between years of experiment. In the first year the variety Pobeda had the highest value of spike harvest index (80.93%) and the Evropa 90 had the lowest SHI (75.67%), while in second year of experiment, the variety Zadruga had the highest value of spike harvest index (85.00%) and the Šumadinka had the lowest SHI (75.50%). Differences of SHI in wheat varieties are due to response of genotypes to environmental factors as well as interaction of genotype/environment.

Key words: Wheat, Variety, Variability, Spike Harvest index

1. INTRODUCTION

Wheat represents staple plant species for food consumption which grown on more than 218 million hectares and over 720 billion tons seed yield (FAOSTAT, 2016). Wheat production is compromised by limited arable land resources, genetic potential of varieties for yield, breeding technology, environmental factors, and will become a greater problem given the global warming trend, predicted to increase by up to 2 °C by 2050, which could lead to greater yield losses if it continues in the future, increasing temperature by up to 2 °C by 2050, which could lead to further yield losses (IPCC, 2013; Asseng et al., 2015). This is indicated by data on a decrease in the period 1980-2010 by 5.5% of world wheat production due to global temperature increase (Lobell et al., 2011). The environmental influence, especially high temperature, water deficit and drought stress are seriously limiting yield of wheat (Dodig et al., 2008; Pradhan et al., 2019). Wheat breeding and the creation of varieties with increased capacity of productivity components and adaptive capacity for future climate change conditions play a significant role in maintaining high wheat production. In wheat plants the large number of spikes, number of spikelets and seeds spike^{-1}, seed mass spike^{-1}, thousand mass spike^{-1}, are important roles in forming yield. Also, the spike length has a strong indirect influence on yield through number of spikelets spike^{-1} and further on number of seeds, size and mass of seeds (Zečević et al., 2004). There are differences in determining the impact number of spike per plant and mass of spike per plant based on negative correlation of size of spike and number of spikes.

In breeding program in the aim of creating variety with high yield, the concept of plants contains more productive tillers, more spikes, spikelets spike^{-1}, seed spike^{-1}, mass of seed spike^{-1} (Knežević et al., 2014, 2020). The genetic improvement of is expressed through increase distribution of photosynthetic products into seed than in vegetative biomass which results in increasing harvest index (HI) and yield potential (Knežević et al., 2015a). The genetic improvement of HI and yield potential can be achieved through the increasing seed number per unit area, which is an indicator of spike fertility (Abbate et al., 2013). In addition to seed number per unit area, an increase in potential seed mass is also significant (Calderini et al., 2013). This indicates that model plants need to have large spike, spikelets spike^{-1}, and high mass (Knežević et al., 2011, 2019), especially high mass of seed spike^{-1} (Knežević et al., 2015b). The ratio of seed mass spike^{-1} and mass of spike variate due to number of fertile florets as well number of seeds spike^{-1}. This indicates efficiency of transport and translocation of dry matter through vessel bundles (phloem and xylem) to spike and seed of spike, as well as indicate index of receptive capacity of seed spike^{-1} and post-anthesis photosynthetic capacity of stem. One of the potential traits to increase seed mass is spike harvest index (SHI), of which genetic base is not clearly known yet (Pradhan et al., 2019).

The aim of this investigation is study of variability of seed spike index in wheat vatieties grown under different environmental conditions.

2. MATERIALS AND METHODS

In this study included 20 divergent winter wheat varieties, selected in Institute of field and vegetable crops Novi Sad and in Centre for Small grains in Kragujevac. These varieties grown on experimental field in Kraljevo in two vegetative season 2015/16 and 2016/17. The experiment set up in randomized block design in three replications. The seeds of varieties were sown at the distance of 0.10 m in rows of 1.0 m length with the distance of 0.2 m. For analysis of spike harvest index determined in proportion of seed mass spike^{-1}/mass of spike, 60 plants in full maturity stage (20 plants per replication) were used. Based on the obtained average values of the mass of the seed and mass of spike, the spike harvest index is calculated according to the formula:

$$\text{Spike index (\%)} = \frac{\text{mass of seeds}^{-\text{spike}}}{\text{mass of spike}} \text{ x } 100$$

Obtained data were processed by using the MSTAT C 5.0 version for analysis of variance by the mono factorial system for each year. The significant differences between the average values were estimated by F-test values. The analysis of variance was performed according to a random block system with one factor and significant differences among cultivars according to spike harvest index were tested by means of test value of LSD $_{0.05}$ and LSD $_{0.01}$.

2.1. Weather conditions in the vegetation period

The mean values of temperature and amount of precipitation were different in two years of experiment (2015/16 and 2016/17) and in the long-term period (2000-2010). In the first year during vegetative season, the average temperature was 9.9 ^{0}C and the total rainfall was 651 mm, which is significantly higher than in the second year as well than in the ten years period. The average temperature in the second year during the growing season was 8.7 ^{0}C and similar to the ten years period, while the total precipitation 523.1 mm was significantly higher than in the ten years period. During the seed filling phase of plants in the first year in April the average temperature was higher and in May the average precipitation was higher and favorable than in second year of experiment and then in ten year period (Table 1).

Table 1. Average monthly temperatures and total monthly precipitation in Kraljevo (www.hidmet.gov.rs)

Parameter	Period	Oct	Nov	Dec	Jan	Feb	March	April	May	June	Xm	Total
Temperature ^{0}C	2015/16	11.6	7.3	3.3	-0.1	8.8	7.8	14.1	15.5	21.3	9.96	89.64
Temperature ^{0}C	2016/17	10.6	6.8	0.0	-4.7	5.2	10.8	11.1	16.8	22.1	8.74	78.66
Temperature ^{0}C	2000-2010	11.8	6.4	1.7	-0.1	2.6	5.9	11.6	16.4	20.4	8.5	76.5
Precipitation (mm)	2015/16	56.8	64.0	9.0	86.2	52.7	157.9	39.9	135.9	48.6	72.3	651.0
Precipitation (mm)	2016/17	84.1	77.6	9.4	22.0	35.0	57.0	82.0	100	56.0	41.1	523.1
Precipitation (mm)	2000-2010	61.0	44.3	44.6	30.0	29.9	33.2	52.9	52.6	69.3	46.4	417.8

3. RESULTS AND DISCUSSION

The spike harvest index varied from 75.67% in Evropa to 80.93% in Pobeda variety with average value of 78.45% in the growing season of first year of experiment. The values of spike harvest index in second year of experiment varied from 75.5% in Šumadinka to 81.67% in Evropa and Dična variety with average value 78.94% of all varieties (Table 2). Wheat varieties with higher spike harvest index (SHI) should be characterized by high number of seed spike^{-1} and a high seed mass spike^{-1}, on which values have influence of genotypes and their plasticity and response to environmental conditions.

In previous research of ten wheat cultivars the spike harvest index varied depend on genotypes and environmental condition in vegetation season from the 75.9% to 81.9% in first year and from 76.6% to 83.1% in second year with average value 79.9% of all varieties. The study of spike harvest index in 22 wheat genotypes showed its variation in range from 0.68 to 0.91 Petrović et al. (2002). The spike harvest index varied in dependence of system of wheat growing. So, in study spike harvest index in wheat (Grčak et al., 2019a) found in average 75%, in sole crop of winter wheat and 71.2% in intercrop (wheat/pea), while in spring wheat varieties spike harvest index was 71.9% in sole crop and 70.8% in intercrop wheat/pea (Grčak et al., 2019b).

The spike harvest index is the value of ratio seed mass spike^{-1} and mass of spike. In this study the seed mass spike^{-1} varied in the range from 2.63 g in Zadraga to 3.53 g in Milica cultivar with average value 3.15 g in first year of experiment. The values of seed mass spike^{-1} in the second year of experiment varied from 2.48 g in Agrounija to 3.14 g in KG-75 variety and average value was 2.87 g. The mass of spike varied in the range from 3.3 g in Zadruga to 4.49 g in Milica variety with average value 3.97 g in first year of experiment. The values of mass of spike in vegetation season of the second year of experiment varied from 3.20 g in Alfa to 3.92 g in Oplenka and 3.90 g in KG-75 variety and average value was 3.61 g.

In comparison wheat varieties which have high value of seed mass spike^{-1} (Milica 3.53 g, in first year and 3.06 g in second year) and mass of spike (Milica 4.49 g in first year and 3.88 g in second year), and other group of varieties with low value of seed mass spike^{-1} (Zadruga 2.63 g in first year and 3.12 g in second year) and mass of spike (Zadruga 3.30 g in first year and 3.67 g in second year), the spike harvest index was similar i.e. in Milica SHI was 78.7% and in Zadruga 9.8% in first year while in second year in Milica spike harvest index was 79.07% and in Zadruga 85%. The similar or higher spike harvest index inn varieties with lower value of seed mass spike^{-1} and mas of spike in comparison with varieties with high value of seed mass spike^{-1} and mas of spike value of seed mass spike^{-1} and mas of spike, indicated that the mass of chaff and rachis was higher in the cultivar Danica, i.e. that a larger amount of assimilate deposited in the chaff and rachis and was not fully translocated into seed (Knežević et al., 2021).

Table 2. Analisys of variance for spike harvest index

Variety	Year		Average
	2015/16	2016/17	
Evropa 90	75.67[f]	81.67[a]	78.67
Dejana	77.33[bcdef]	76.43[gh]	76.88
Sila	77.37[bcdef]	80.27[bcd]	78.82
Omega	80.40[ab]	80.83[bcd]	80.61
Lasta	79.60[abcd]	81.53[bc]	80.56
Milica	78.73[abcdef]	79.07[cdef]	78.90
Partizanka	79.00[abcde]	77.33[efgh]	78.16
Pobeda	80.93[a]	77.00[fgh]	78.96
Dična	79.43[abcde]	81.67[b]	80.55
NSR-5	76.37[ef]	79.00[cdef]	77.68
Alfa	79.33[abcde]	78.33[defg]	78.83
Rodna	78.33[abcdef]	77.33[efgh]	77.83
Agrounija	77.67[bcdef]	75.53[h]	76.60
Zadruga	79.83[abc]	85.00[a]	82.41
KG -75	76.96[cdef]	80.23[bcd]	78.59
Šumadinka	79.47[abcde]	75.50[h]	77.48
Levčanka	79.23[abcde]	79.87[bcde]	79.55
Oplenka	78.77[abcdef]	76.97[fgh]	77.87
Gruža	78.00[abcdef]	76.33[gh]	77.16
KG-56	76.57[def]	78.87[defg]	77.72
Average	78.45	78.94	-

Generally, in average all studied wheat varieties in second year expressed higher values of seed mass spike^{-1} as well mass of spike than in the second year. However, spike harvest index was higher in the second year in 11 variety (Evropa 81.67%, Sila-80.27%, Omega-80.83%, Lasta-81,53%, Milica-79.07%, Dična-81.67%%, NS Rana5-79.0%, Zadruga-85.0%, KG 75-80.23%, Levčanka-79.87%, KG 56-78.87%) than in the first year (Evropa 75.67%, Sila -77.37%, Omega-80.40%, Lasta-79,60%, Milica-78.73%, Dična-79.43%%, NS Rana5-76.37%, Zadruga-79.83 %, KG 75-76.96%, Levčanka-79.23%, KG 56-76.57%).

Variation of the spike harvest index in one variety under different conditions shows the manifestation of a different response to eco-climatic conditions as an expression of the interaction of genotype and external environment. This adaptation of genotypes to different environmental conditions indicates the ability of a variety to express its genetic potential in specific environmental conditions (Thungo et al., 2019; Subira et al., 2015). The variation of spike harvest index depends on environmental conditions indicate genotype capacity for adaptability to change environmental condition, i.e. indicate different efficiency for adsorption, utilization of water and minerals and different efficiency of photosynthesis and translocation and partitioning of assimilates into seed and vegetative part (Rivera-Amado et al., 2019). The identification genetic loci (at the 1B, 2B, 3B, 3D, 4A, 5A, 6A, 6D, 7A, 7D) associated with spike harvest index as well spike fertility contribute to detect markers that are functionally linked to seed yield and harvest index (Pradhan et al., 2019). In early studies showed that correlation between spike HI, estimated on the basis 10 spike sample and plot harvest index, was low and statistically nonsignificant. Based on this study, one could not recommend using spike HI as a predictor of plot harvest index (Hucl and Graf, 1992). Moreover, Pradhan et al. (2019) in study found significant genotypic variation for SHI across all environments and that SHI was positively correlated with spike fertility (0.32 to 0.41) and seed yield (0.24 to 0.49) and harvest index. Also, they reported that SHI have the potential to increase the efficiency of breeding programs aimed at optimizing yield of seeds and its major components in wheat upon validation.

In this study were found significant genotypic variation for spike harvest index in second year environments. The analysis of variance established that the differences between the varieties for the spike harvest index were significant and highly significant. Differences between vegetation seasons for spike harvest index in varieties, indicate that there is an influence of environmental factors on the expression spike harvest index. They established significant differences in the average values of spike harvest index, indicating genetic divergence of varieties (Table 3).

Table 3. Analisys of components of variance for spike harvest index in two vegetation seasons

Source of variance		First year- Vegetation season 2015/16					Second year-Vegetation season 2016/17				
	df	*SS*	*MS*	*F*	*Lsd0,05*	*Lsd0,01*	*SS*	*MS*	*F*	*Lsd0,05*	*Lsd0,01*
Genotypes	2	5.102	2.551	0.7238^{ns}	-	-	24.864	12.432	5.5227**	-	-
Repetitions	19	114.803	6.042	1.7142^{ns}	3.209	4.386	347.775	18.304	8.1311**	2.564	3.505
Error	38	133.944	3.525	-	-	-	85.542	2.251	-	-	-
Total	59	253.850	-	-	-	-	458.182	-	-	-	-

ns-nonsignificant differences; p<0.05*, p<0.01**

In study Knežević et al. (2021) found that variation of spike harvest index determined by greatest influence of genotype (25.63%) while Petrović et al. (2002) found higher impact of environment. The environment conditions had the highest impact on seed mass spike^{-1} (38.35%) and also on the mass of spike (48.63%). Also, variation of values of temperature, precipitation, nutrition has influence on increasing of capacity of spike (Petrović et al., 2008; Knežević et al., 2016) and seed yield (Marijanović et al., 2010).

On the base of obtained values for spike harvest index the five clusters of similar varieties were differentiated in the first year (2015/16) and one variety (Evroppa) that was the most distant in similarity from other varieties in all five clusters. The first cluster contains 6 varieties, in which the greatest similarity is shown by Dejana and Sila, with which Agrounija is most similar at the highest hierarchical level, followed by Rodna and Gruža, and at an even greater distance by the KG 75 variety. The second cluster represents a pair of varieties NS rana 5 and Kragujevčanka 5. The third cluster contains 5 varieties, within which the greatest similarity was shown by Dična and Šumadinka, with which the pair of varieties Alfa and Levčanka showed a higher hierarchical level, and with these four varieties the variety Lasta showed similarity at a greater distance. The fourth cluster contains four varieties, among which the varieties Milica and Oplenka had a high level of similarity, and which were like the varieties Partizanka and Zadruga. The fifth cluster represents a pair of mutually similar varieties Omega and Pobeda. Among those five clusters the third and fourth cluster varieties showed the greatest similarity, then the first and second clusters, and at the next hierarchical level, the third and fourth showed similarity with the first and second, with which the fifth cluster showed similarity at a greater distance and the lowest similarity with all varieties showed the variety Europa (Figure 1).

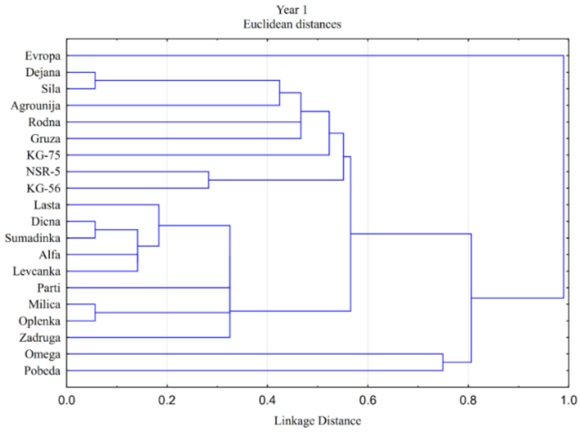

Figure 1. Similarity of wheat genotypes according to the spike harvest index in the vegetation 2015/16 season

In second year (2016/17) the six cluster mutually sim ilar varieties were established and one variety (Zadruga) that was the most distant in similarity from other varieties in all five clusters. The first cluster contains two varieties Evropa and Dična, the second cluster contains four varieties of which the greatest similarity was between the varieties Sila and Kragujevacka 75 with which the varieties Levčanka and then Omega was with a lower degree of similarity. The third cluster has four varieties of which Milica and NS rana 5 showed a high degree of similarity, and with them the varieties Kragujevčanka 56 showed similarity and then Alfa with a lower degree of similarity. The fourth cluster contains two varieties Dejana and Gruža. The fifth cluster contains four varieties of two mutually similar varieties and Partizanka and Rodna and Pobeda and Oplenka. The sixth cluster has two mutually similar varieties Agrounija and Šumadinka. Among those six clusters, the highest similarity was between the fourth and fifth clusters showed the greatest similarity, then the first and second. The same level of similarity was shown by the third cluster with formed cluster from the first and second, and the sixth cluster with the formed cluster from fourth and fifth clusters, and these two groups of three clusters are like each other at a greater distance. The least similarity with all varieties was shown by the variety Zadruga (Figure 2).

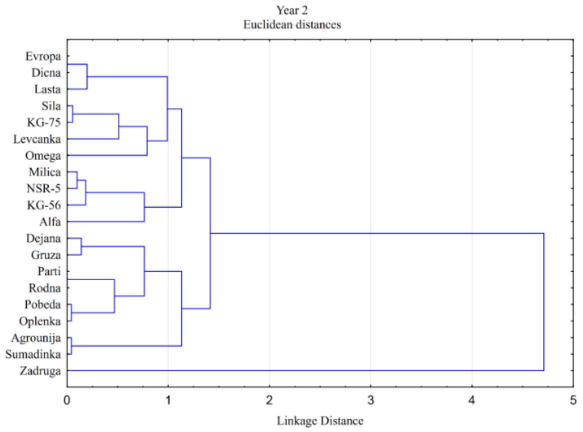

Figure 2. Similarity of wheat genotypes according to the spike harvest index in the vegetation 2016/17 season

In these studies, the examined wheat genotypes showed a high spike harvest index, which on average varies between 76,60% and 82.41% in two vegetation season. In other study of wheat varieties, similar values of variation in spike harvest index were found (Knežević et al., 2021). The high values of spike harvest index indicate high number of seeds spike^{-1}, harvest index what lead high yield of seeds. The significant positive association of spike harvest index found with mass of spike 0.57*, number of seeds spike^{-1} 0.62**, thousand seed mass 0.63** and stem harvest index 0.68** found in study of 61 advanced lines and five Iranian varieties (Moosavi et al., 2020), which is in agriment with previous results reported in reseach (Rahman et al., 2016). For increasing the spike harvest index as well other component of yield, the greatest contribution has soil moisture, mineral nutrition and accessibility of mineral elements for absorption, temperature, light and photosynthetic process and reutilization and translocation of organic matter (Dodig et al., 2008; Rivera-Amado et al., 2019).

4. CONCLUSIONS

In this study were determined significant differences between wheat varieties and between the years of experiment according to spike harvest index in both vegetative season. The variation of spike harvest index in the same variety in two vegetation season indicate genotype's response to different environmental conditions. The highest values of spike harvest index (85.1%) in Zadruga variety expressed in the second experimental investigation, while the least (75.50%) in wheat Levčanka in the second year of experimental investigation. The differences between genotypes were significant and highly significant for spike harvest index. Genetic factors, environmental factors and genotype/environment interaction had an influence on the manifestation spike harvest index.

5. ACKNOWLEDGEMENTS

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