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Original scientific paper

GENOTYPE AND LOCATION INTERACTION FOR YIELD AND MORPHOLOGICAL TRAITS IN RICE (*Oryza sativa* L.)[#]

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The objectives of this study were to determine the genotype and location interaction for paddy yield and morphological traits. Two field trials were conducted in a randomized block design with 3 repetitions in the Kocani rice producing region in two locations in 2014. The Turkish varieties, Halilbey, Gala and Gönen and standard San Andrea were used in the experiment. The combined variance analysis for paddy rice yield, biological yield, harvest index (HI), plant height, panicle length and the number of panicles per m^2 has been performed. Highly significant differences among examined genotypes and locations were found for almost all the traits. Genotype × location interaction was significant only for the biological yield and number of panicles per m^2. The highest means for most of yield traits were observed for Gala and Halilbey varieties. Due to their performances, Halilbey, Gala and Gönen can be recommended for the rice production in the Republic of Macedonia.

Key words: rice variety, genotype × location interaction, yield trait, morphological trait

INTRODUCTION

In order to promote Macedonian rice production, one of the measures is the introduction of new rice varieties. The main criteria for their selection are high yielding and quality performances, but also, adaptability to local environmental conditions and growing practices.

Beside the Macedonian registered rice varieties (No. 51, No. 69, Osogovka, Kochanski, Biser 2, Ranka, Nada 115, Prima riska and Montesa), in the entire production, the Italian rice varieties dominate. The oldest introduced and registered varieties are Monticelli, R-76/6, Drago and Baldo (prevalent during the nineties), then the last fifteen years San Andrea was the most widespread. Within 2009–2013, the Italian varieties: Galileo, Bianca, Brio, Ellebi, Opale, Arpa and Onice entered in the domestic rice production.

In 2013, the introduction of fourteen Turkish rice varieties (TR-2121, TR-2024, TR-1981, Paşalı, Çakmak, Kızıltan, Gönen, Kırkpınar, Tunca, Halilbey, Durağan, Gala, Hamzadere and Efe) started through a joint Turkish-Macedonian project "Development of production and quality of rice in the Republic of Macedonia 2013-2014" [1]. Three of these varieties (Gönen, Halilbey and Gala) were registered in the Macedonian National list of Varieties in 2016.

In all these stages, the new varieties were the results of many fields and laboratory investigations, with special attention to their yield performances and morphological traits [2–9].

Paddy yield was always in the focus of all these studies, since it considered as one of the most important traits for the rice growers, besides the quality traits. In some trials, several introduced varieties (Brio, Ellebi, Opale, Arpa and Onice) were lower yielding, compared to control varieties Prima riska – Macedonian variety and R-76/6, Italian domesticated variety [6, 7]. In other research, where San Andrea was used as a control variety, the Turkish rice varieties Kızıltan, Gala, Halilbey, Gönen and Paşalı achieved better paddy yield than control [9].

Plant height of the new rice varieties was also of particular interest. Over the years, in Macedonian

[#]Dedicated to academician Gjorgji Filipovski on the occasion of his 100th birthday rice growing, taller varieties dominated [5, 6, 8]. Beside their yielding ability, they were not very suitable for intensive production systems mostly because of their susceptibility to lodging, especially in case of high doses of inorganic fertilizers. Therefore, during the recent variety selection special attention was done to semi-dwarfs, high-yielding and good quality rice varieties.

Although biological yield, panicle length and the number of productive panicles per m^2 were regularly explored at the national level [5, 6, 8] - up to now, harvest index of rice has not been the subject of research under the conditions of the Republic of Macedonia.

For grain crops, harvest index (HI) is the ratio of harvested grain to total dry matter, and this can be used as a measure of reproductive efficiency. In agronomic terms, HI is calculated as the ratio of harvested product to total aboveground biological yield, which is an economic HI [10]. Harvest index of rice is the result of various integrated processes with involvement of the number of panicles per unit area, the number of spikelets per panicle, the percentage of fully ripened grains, and 1,000 grain weight [11]. HI is one of the yield determining factors. The partitioning of dry matter to grain and straw varied among the genotypes [12]. The HI of crop plants has increased over time due to breeding for higher yield and more recently, specifically for HI. Shorter-statured, modern crop cultivars have higher harvest indices than their taller forebears, although total dry matter production is most often very similar [10]. However, the genetic control of the harvest index plays an important role in crop production [13].

The performance of the cultivar is mostly influenced by genotype, growth environment and the response of genotype to the present environment [14]. The study of genotype × environment interaction is critical for accurate cultivar evaluation in large multi-environmental trials. Cultivars that exhibit high levels of mean performance and stability across a wide range of environmental conditions are desirable for rice production [15].

A genotype × environment interaction may be defined as a change in the relative performance of a "character" of two or more genotypes measured in two or more environments. Interactions may therefore involve changes in rank order between environments and changes in the absolute and relative magnitude of the genetic, environmental and phenotypic variances between environments. These changes in rank order and in variances are found separately and together [16].

Regarding the rice grain yield, analysis of variance showed highly significant differences among genotypes (G), environments (E) and G × E interaction in multi-location trials with several rice genotypes [17]. The significant G × E interaction effect demonstrated that the genotypes responded differently to the variation in the environmental condition of the testing sites and grain yield fluctuated accordingly. This indicates the necessity of multi-location testing of genotypes before recommending for general cultivation.

The aims of this study were to determine the influence of the genotype, location and their interaction on several yields and morphological traits on the rice varieties Halilbey, Gala, Gönen and San Andrea.

MATERIALS AND METHODS

Three newly registered Turkish rice varieties: Halilbey, Gala and Gönen were included in the experiment, together with the standard variety San Andrea (Italian rice variety, widely used and domesticated in Macedonian rice production). During 2014, two identical field trials were set up on two locations within the entire Kocani rice-producing region. Location 1 was in Cesinovo village, on a private rice plot, while location 2 in Kocani, on the field of the Rice experimental Station Kocani, unit of the Institute of Agriculture, Skopje. The distance between locations is 15 km and both of them have continental sub-Mediterranean climate characteristics [18]. Thus, they don't differ significantly regarding the climatic conditions and the data presented in Table 1 for Kocani cite are considered as representative for both locations as well as for the entire rice producing region in the country.

The soil characteristics of the experiment locations were presented in Table 2. As it is seen in the table, they have different soil contents.

The experiment was designed as a randomized blocks system with 3 repetitions and $5m^2$ plot size. The seeding was manual - wet seeds were broadcasted into standing water. The seed rate was 500 seeds per m^2. Standard production technology was applied during the rice cultivation period. The data were recorded for plant height, panicle length, biological yield, harvest index, the number of panicle per m^2 and paddy yield.

Using IBM SPSS Statistics 23 statistical program, the variance analysis was conducted to determine the differences among the varieties for the examined traits and interaction between location and genotype. The differences among mean values were tested by using LSD test.

Table 1. The average monthly temperatures and monthly sums of rainfalls during the rice vegetation period in Kocani in 2014

Year	Months							Average	
	IV	V	VI	VII	VIII	IX	X	per year	per vegetation
Average monthly temperature [Cº]									
2014	12.4	16.8	20.8	23.2	23.8	18.3	13.8	13.8	18.4
Average 1998/2012	13.8	18.6	22.9	25.6	25.1	20.0	14.7	14.1	20.1
Average monthly maximum temperature [Cº]									
2014	18.0	23.0	28.1	30.9	31.8	25.0	20.7	20.1	25.4
Average 1998/2012	19.2	23.9	28.7	31.6	31.5	26.2	20.2	19.4	25.9
Average monthly minimum temperature [Cº]									
2014	7.4	10.8	14.0	16.5	16.6	13.4	8.7	8.5	12.5
Average 1998/2012	5.7	10.1	13.3	15.1	15.0	10.8	6.8	6.3	11.1
Monthly sum of rainfalls [mm]									
2014	121.0	92.0	116.0	65.0	31.0	89.0	37.0	794.0	551.0
Average 1998/2012	39.7	49.4	54.5	27.6	34.5	42.7	60.4	489.5	308.9

Table 2. Chemical properties of soils from Cesinovo and Kocani

Location	Depth [cm]	pH		$CaCO_3$	Easily available mg/100g of soil	
		H_2O	nKCl	%	P_2O_5	K_2O
Cesinovo	0–20	7.9	6.8	1.24	26.51	24.86
	20–40	7.6	6.6	1.44	22.72	19.74
Kocani	0–20	5.9	5.1	0	16.88	14.03
	20–40	6.2	5.6	0	12.66	11.15

RESULTS AND DISCUSSION

The variance analysis results (Combined ANOVA) showed highly significant differences ($P \leq 0.01$) among investigated genotypes for all the traits, except for the harvest index where the differences among genotypes were significant ($P \leq 0.05$) (Table 3). The differences between locations were not significant only for panicle length, while for all the other characteristics were highly significant. Genotype × location interaction was highly significant ($P \leq 0.01$) only for biological yield and significant ($P \leq 0.05$) for a number of panicles per m^2.

The non-significant G × L interaction for grain yield in this research contradicted the findings of Tariku et al. [19], Upreti et al. [17], Bose et al. [20], Sürek et al. [21] and Blanche et al. [15]. In their studies, they all revealed highly significant genotype × location interaction for rice grain yield where the genotypes interacted considerably with environmental conditions. Also, the non-significant G × L interaction for plant height (Table 4) in this study differs from the results of Tariku et al [19], who reported highly significant G × E interaction for this trait on the tested lowland rice varieties.

In this study, the paddy rice yield varied between 6.10 t/ha (San Andrea, Cesinovo) and 12.27 t/ha (Gala, Kocani), as presented in Table 4. The highest average paddy yield was obtained with Gala (9.96 t/ha) and the lowest with San Andrea (7.42 t/ha). The other Turkish varieties Halilbey and Gönen also achieved higher mean paddy yield than standard San Andrea, but not significantly. The location of Kocani provided better environmental conditions for grain yield to all the examined varieties than the location Cesinovo, as it is obvious also from Figure 1. The reported potential for paddy rice yield of the related varieties from the Trakya Agricultural Research Institute [22] was: 9–10,000 kg/ha for Gala, 11.000 kg/ha for Halilbey and 8.500 kg/ha for Gönen. Akay et al. [14] recorded similar results for Gala rice variety, as one of the best yielding cultivars with 6.623 kg/ha.

Table 3. Combined ANOVA for investigated traits of rice varieties

Sources of variation	DF	Paddy rice yield	Biological Yield	Harvest index	Plant height	Panicle length	Number of panicles per m^2
		Mean Squares					
Replication	2	0.267	1.5100	0.001	61.976	1.018	424.5
Location	1	72.84 **	2836.461 **	0.031 **	1985.62 **	0.027	273920.67 **
Genotype	3	7.332 **	29.071 **	0.005 *	369.13 **	12.181 **	3818.56 **
Genotype × location	3	1.053	22.515 **	0.001	2.429	0.314	1117.889 *
Error	14	0.593	2.6250	0.001	13.344	0.749	317.357
Total	24	–	–	–	–	–	–

* significant at level P ≤ 0.05, ** significant at level P ≤ 0.01

Table 4. Mean values for examined traits of rice varieties

Genotypes (Varieties)	Locations	Paddy rice yield [t/ha]	Biological Yield [t/ha]	Harvest index	Plant height [cm]	Panicle length [cm]	Number of panicles per m^2
	Cesinovo	6.10	18.67	0.32	108.10	16.70	287.00
San Andrea	Kocani	8.73	35.77	0.25	125.13	16.10	483.33
	Mean	**7.42 b**	**27.22 ab**	**0.29 a**	**116.62 a**	**16.40 ab**	**385.17 b**
	Cesinovo	7.39	16.53	0.33	93.40	15.23	232.67
Halilbey	Kocani	10.58	41.82	0.30	112.33	15.67	486.00
	Mean	**8.98 ab**	**29.18 a**	**0.31 a**	**102.87 b**	**15.45 ab**	**359.33 c**
	Cesinovo	7.65	18.18	0.41	92.37	14.33	321.33
Gala	Kocani	12.27	42.75	0.30	109.57	14.50	516.33
	Mean	**9.96 a**	**30.47 a**	**0.35 a**	**100.97 b**	**14.42 b**	**418.83 a**
	Cesinovo	6.33	15.45	0.36	104.20	17.90	269.67
Gönen	Kocani	9.82	35.46	0.29	123.80	17.63	479.67
	Mean	**8.08 b**	**25.46 b**	**0.33 a**	**114.00 a**	**17.77 a**	**374.67 b**
	LSD (0.05)	*1.99*	*3.60*	*0.38*	*7.08*	*2.72*	*13.32*

Distinct letters in the row indicate significant differences according to LSD test (P ≤ 0.05)

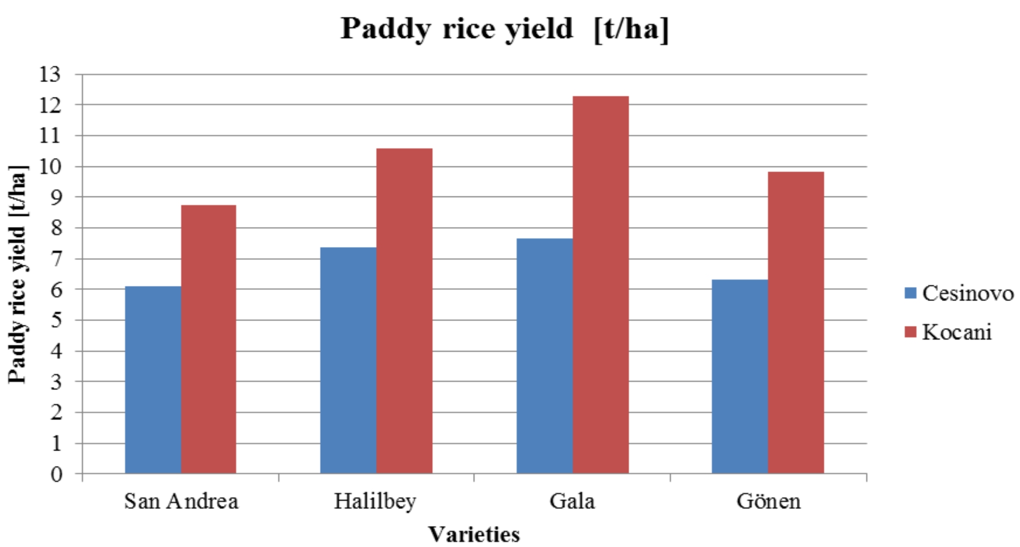

Figure 1. Paddy rice yield of the examined rice varieties

The mean biological yield of the examined varieties (Table 4) ranged from 15.45 t/ha (Gönen, Cesinovo) to 42.75 t/ha (Gala, Kocani). Gala achieved the highest mean biological yield (30.47 t/ha), significantly higher only from the lowest mean found in Gönen (25.46 t/ha). The control variety San Andrea did not differ significantly from Turkish rice varieties, regarding the mean value of this trait. Biological yield values were strongly affected not only by genotype but mostly by the environmental conditions (location) and it was the only trait with highly significant genotype × location interaction (Table 3). In general, higher total biomass in all cultivars was obtained in the Kocani location compared to Cesinovo (Figure 2). In Kocani, the highest value was observed in Gala (42.75 t/ha), while in Cesinovo, the most abundant biomass was produced by San Andrea (18.67 t/ha). Gönen was the variety with the lowest biological yield in both locations (15.45 t/ha in Cesinovo and 35.46 t/ha in Kocani).

Since biological yield was significantly affected by location and genotype × location interaction (Table 3), it suggests genotypic sensitivity to differences in environmental conditions at the two examined locations [13]. In some other trials conducted in the Kocani region during 2013 and 2014 [9], in both years of research, San Andrea produced significantly higher biological yield than Halilbey, Gala and Gönen. Entirely, Unkovich et al. [10] reported maximum values for rice biological yield (DM) of 31.6 t/ha for dryland conditions of Australia.

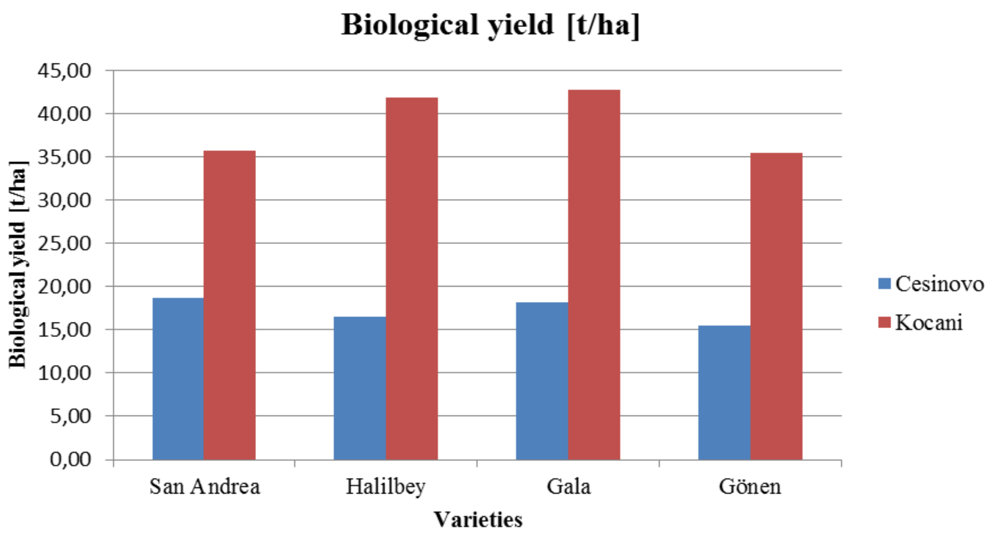

Figure 2. Biological yield of the investigated rice varieties

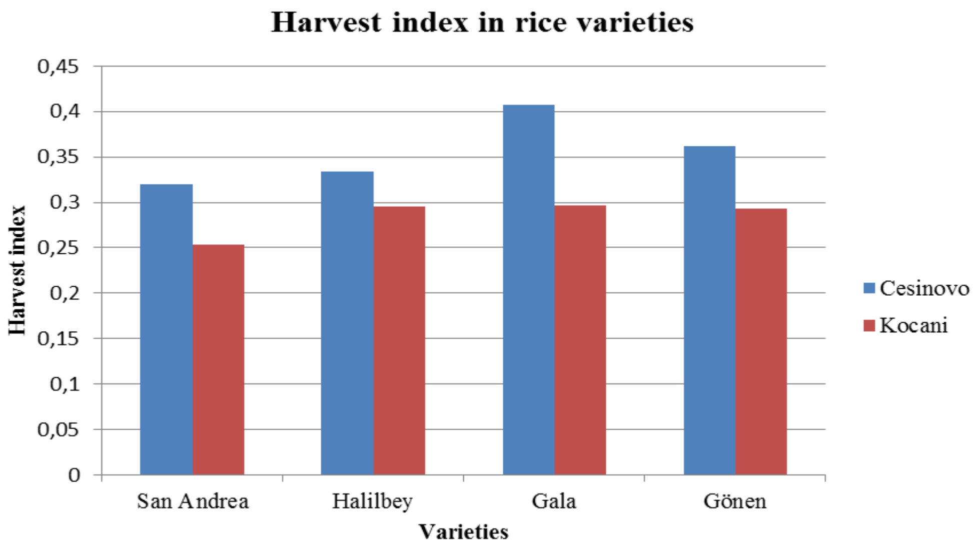

Figure 3. Harvest index in the rice varieties

The values of the harvest index varied between 0.25 (San Andrea, Kocani) and 0.41 (Gala, Cesinovo). The highest mean HI was observed in Gala (0.35) and the lowest (0.29) in San Andrea, but the differences among all cultivars were not significant. All the cultivars in the Cesinovo location gained better HI than in Kocani (Figure 3). In both locations, Gala achieved the highest and San Andrea the lowest harvest index. Harvest index (HI) was the only trait where the variation among cultivar was mainly influenced by the environment (location – highly significant at level $P \leq 0.01$), less than by genotype (significant at level $P \leq 0.05$) and no significantly influenced by interaction genotype × location (Table 3). These findings were in accordance of those of Turner et al. [23], related to the conditions of Australia, where the environment rather than genotype was seen as the major determinant of harvest index for most field crops for a given site × year × genotype. Li et al. [13] appointed that the crop harvest index is also highly influenced by environmental factors, such as soil condition and temperature. In their research on two locations, they obtained means of harvest index (expressed in %) of 30.44 % and 38.98 %. According to Jun [24], large variation was observed for harvest index in rice: about 0.25 among wild species, 0.30 among tall cultivars and more than 0.40 for semi-dwarf cultivars.

Plant height of the investigated varieties (Table 4) varied between 92.37 cm (Gala, Cesinovo) and 125.13 cm (San Andrea, Kocani). The tallest plants on average were observed in San Andrea (116.62 cm), while the shortest was in Gala (100.97 cm). Actually, two groups of cultivars differentiated regarding the plant height. San Andrea and Gönen were taller and did not differ significantly, Gala and Halilbey were shorter, also without significant differences between them. In the same time, among the means of each variety from a different group, significant differences were stated. Regarding different locations, both in Cesinovo and Kocani, the ranging for the plant height was the same: San Andrea > Gönen > Halilbey > Gala. The bigger values for plant height were observed in Kocani (Figure 4). The similar results were obtained in another study in the Kocani region during 2013 and 2014, conducted by Andov et al. [8] where the varieties Halilbey, Gala and Gönen were significantly shorter than San Andrea in both years of the research. As a conclusion, the registration of these three Turkish rice varieties (especially Halilbey and Gala), was a positive step from the aspect of including new rice genotypes with lower plant height in the Macedonian rice farming, suitable for intensive production systems.

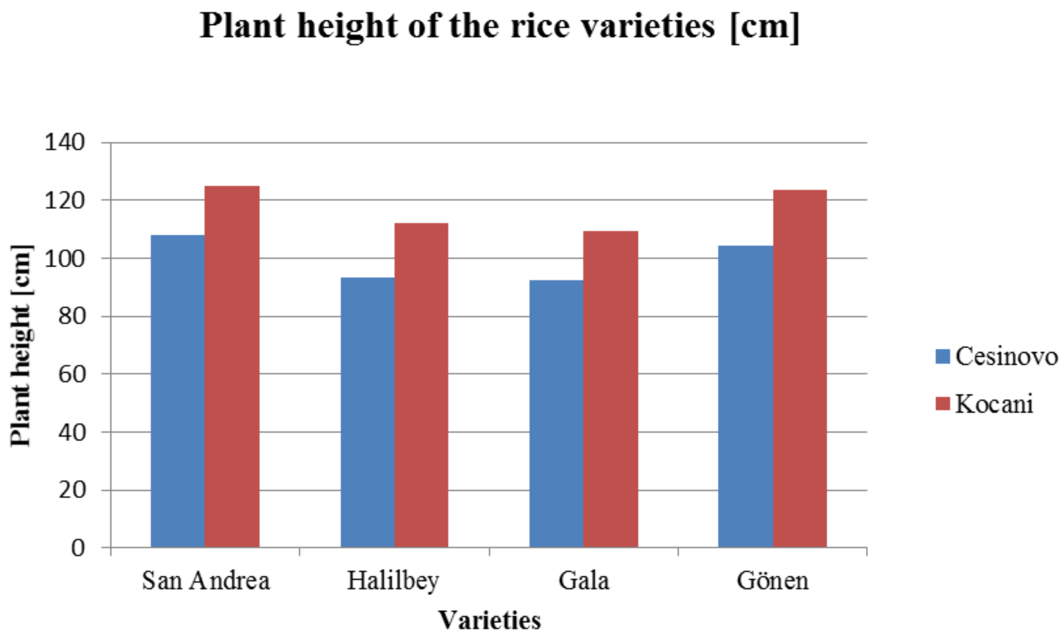

Figure 4. Plant height of the examined rice varieties

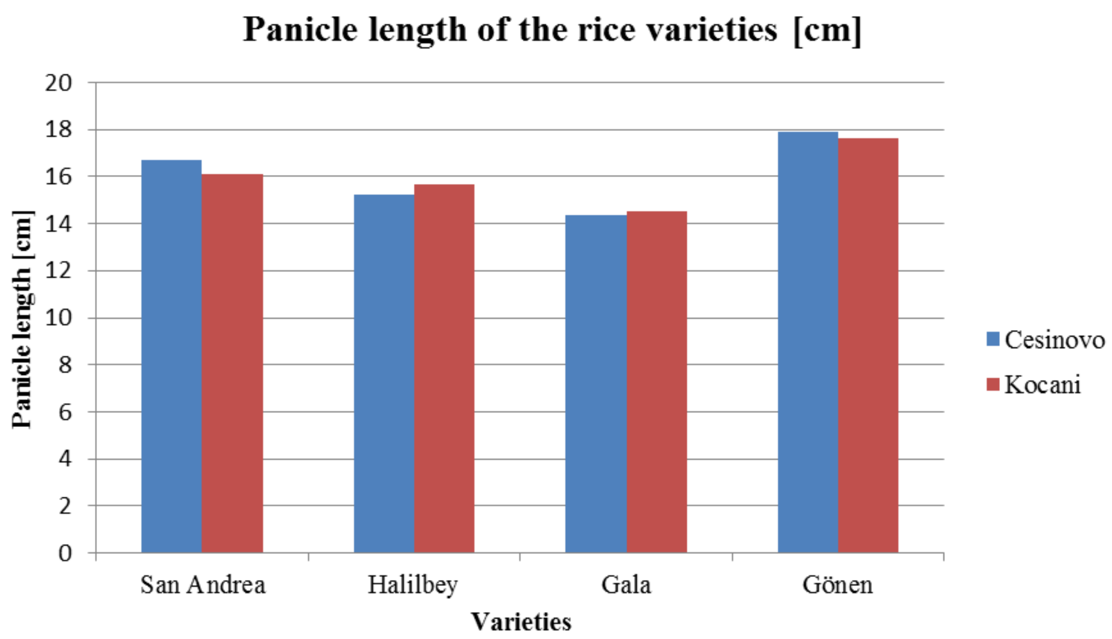

Figure 5. Panicle length of the investigated rice varieties

The number of panicles per m^2 in the investigated rice varieties (Table 4) varied from 232.67 (Halilbey, Cesinovo) to 516.33 (Gala, Kocani). Gala had the highest mean value (418.83) that was significantly higher than all the other varieties, while the significantly lowest was the mean number of panicles per m^2 in Halilbey (359.33). The comparison of the locations showed greater values in Kocani than in Cesinovo (Figure 6). Gala reached the highest values in both locations (321.33 in Cesinovo, 516.33 in Kocani). The lowest panicles number in Kocani (479.67) and Cesinovo (232.67), was observed for Halibey and Gönen, respectively. In this study, the analysis of variance for the number of panicles per m^2 showed significant genotype × location interaction, highly significant genotype and location variations (Table 3). In another two-years research conducted in the Kocani region, for San Andrea, it was observed a higher average number of panicles per m^2 (527.17) compared to Gala (492.00), Halilbey (489.17) and Gönen (448.50) [8].

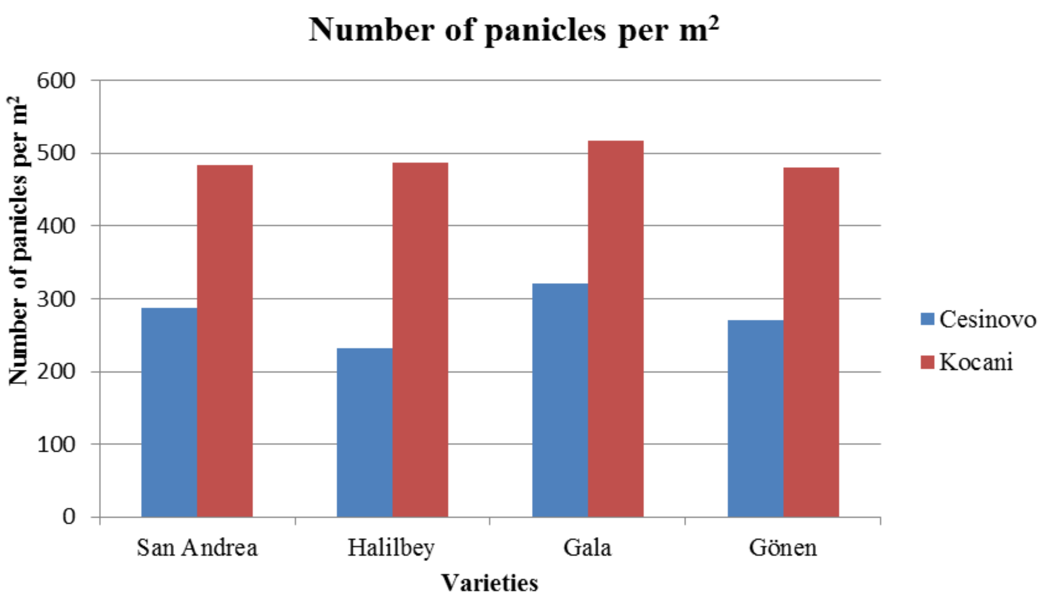

Figure 6. Number of panicles per m^2 in the examined rice varieties

Taking into account all the results obtained in this study, the general conclusion could be done in the sense that the genotype and location had a highly significant influence on paddy yield, biological yield, plant height and a number of panicles per m^2. Significant differences among genotypes by genotype × location interaction were found only for biological yield ($P \leq 0.01$) and a number of panicles per m^2 ($P \leq 0.05$).

The newly registered Turkish rice varieties Halilbey, Gala and Gönen, for most of the examined traits showed better results than the standard San Andrea. Especially for Gala, higher mean values for paddy rice yield, biological yield, harvest index and a number of panicles per m^2 were observed. Similar values were found also for Halilbey. These two varieties were significantly shorter – statured compared to San Andrea, which is a desirable characteristic. Gönen had the longest panicles among the varieties and also achieved some better results from San Andrea for other traits (even none significantly).

Regarding all the analyzed performances of Halilbey, Gala and Gönen in this and in some previous studies at the national level, their implementing in the entire rice production in the Republic of Macedonia can be recommended. Also, there is an interest for them to be included in some further investigations.

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ЕФЕКТИ НА ГЕНОТИПОТ И ЛОКАЦИЈАТА ВРЗ МОРФОЛОШКИТЕ СВОЈСТВА КАЈ СОРТИ ОРИЗ

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Целта на испитувањето беше да се утврди влијанието на генотипот, локацијата и нивната интеракција на продуктивните и морфолошките својства на четири сорти ориз. Во 2014, два полски опита (рандомизирани блокови со три повторенија) беа поставени на две локации во кочанскиот регион со турските сорти Halilbey, Gala и Gönen и стандардот San Andrea. Податоците од својствата: принос на арпа, биолошки принос, жетвен индекс, висина на растенија, должина на метличка и број на метлички на m^2 беа обработени по методот комбинирана анализа на варијансата. Кај најголемиот број од својствата беа најдени високо сигнификантни разлики меѓу испитуваните генотипови и локации. Интеракцијата генотип × локација беше сигнификантна само за биолошкиот принос и бројот на метлички. Сортите Gala и Halilbey постигнаа највисоки просечни вредности за продуктивните својства и имаа пониско стебло, како погодни карактеристики. Заради покажаните позитивни особини на различни локалитети во ова испитување, сортите Halilbey, Gala и Gönen може успешно да бидат вклучени во македонското оризопроизводство.

Клучни зборови: ориз; генотип; интеракција генотип × локација; продуктивни својства; морфолошки својства