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Effect of harvest time of paddy on milled rice yield and broken kernels

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Abstract. *The aim of this study was to determine the optimal harvest time to achieve maximum milled rice yield and quality of white rice in some newly introduced Italian rice varieties grown under agro-ecological conditions in the region of Kocani town, Republic of North Macedonia. During the 2014 and 2015, fourteen rice varieties were cultivated to estimate the milled rice yield and broken kernels from three different harvest times. From each rice variety, samples with moisture content between 20-22% (I variant), 18-20% (II variant) and 16-18% (III variant) were taken. From the third harvest variant the highest percentage of milled rice yield (65.23%) was obtained but also the highest rate of broken kernels (12.79%). From the remaining two harvests, almost identical milled rice yields were received (64.19% from the first variant and 64.33% from the second variant), but in terms of broken kernels, there were significant differences. The optimum moisture content during the harvest in order to obtain maximum yield and quality of milled rice ranged from 18% to 20%. The varieties Arsenal, Sprint and Mirko had the most favorable values for milled rice yield and broken kernels.*

Keywords: *Oryza sativa* L., variety, moisture content, milling quality

Abbreviations: CV – coefficient of variation; MC – moisture content; MR – milled rice yield; BK – broken kernels; PCA - Principal Component Analysis

Introduction

Two of the primary measures of milling "quality" are milled rice yield and head rice yield. Milled rice is the component of rough rice produced by removing the hulls, germs and most of the bran; milled rice includes both intact and broken kernels. Milled rice yield is calculated as the mass fraction of rough rice remaining as milled rice. Yield and quality of white rice are complex traits which are directly or indirectly dependent on a large number of inherited properties of the variety, agro-ecological conditions in which the variety is cultivated and the applied technology of paddy production and processing. The main variety properties that affect the yield and quality of white rice are: length of vegetation period, equal kernels ripening in panicle, reaction to unfavorable climatic conditions during the ripening, shape, size and strength of kernel, as well as the ratio of the absorption and desorption of moisture in grain during the ripening time. On the other hand, the environmental conditions also have important impact on rice yield (Li et al., 2018). Furthermore, production practices also can have major impact, for example: time of sowing, the use of nitrogen fertilizers, irrigation, control of diseases and insects, harvest time and machinery used for harvest. Following the harvest, big effect on the milled rice yield and quantity has the imminent treatment of the rice, including paddy drying, conditions and time of paddy storage and milling technology. Among the various factors, harvest time is often indicated as a problem. Too early or too late harvesting of rice leads to greater number of immature or cracked kernels, resulting in more broken milled rice (Firouzi and Alizadeh, 2013). In order to achieve higher rice yield and total milled rice, it is essential to harvest just on time. Harvesting time is an important variable which determines the field yield, total and head yield of rice (Yehia and Ebaid, 2009). Moisture content is perhaps the most important parameter in determining the optimal time to harvest rice (Lu and Siebenmorgen, 1994). Rice moisture content at harvest is one of the most important factors influencing milling quality and overall economic value of rice (Qin and Siebenmorgen, 2005; Thompson and Mutters, 2006; Sadeghi et al., 2012). Paddy is harvested at optimum grain maturity at which the grains have an average moisture content from 20% to 25%. Higher moisture content results in losses from poor grain quality. Lower moisture content results in more losses from shattering (IRRI, 2016).

Numerous studies have addressed the effects of harvest moisture content on milling quality. Different optimal harvest moisture contents have been reported for rice grown under various environmental conditions and for different cultivars (Thompson et al., 1990; Fan et al., 2000; Wang et al., 2004; Siebenmorgen et al., 2007). Mainly, the percentage of broken kernels in white rice increases in all varieties with short and medium grain, when paddy is harvested with moisture content below 20%. Subsequently, the total milled rice yield is reduced. Japonica rice varieties, grown in the Republic of North Macedonia, have intermediate to late vegetation (130-150 days from sowing to harvest) and intermediate to long grain. Usually, the harvest is conducted when the average moisture content in grain is below 18%.

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The main purpose of this research was to determine the optimal harvest time to achieve higher milled rice yield and quality of rice in some newly introduced Italian rice varieties grown in agro-ecological conditions in the Republic of North Macedonia.

Material and methods

The trials were set up in the town of Kocani region, on an experimental area of Rice Institute, Faculty of Agriculture, "Goce Delchev" University – Stip, during 2014 and 2015. In both testing years, a field experiment was set up in a randomized block design, with three repetitions. The size of each experimental plot was 5m^2. Fourteen Italian rice varieties (Arsenal, Nembo, Ronaldo, Galileo, Sprint, Ulisse, Krystalino, Mirko, Sfera, Gloria, Pato, Creso, Vasco and San Andrea) were included in the research as experimental material. San Andrea was used as a standard variety and it is a dominant variety in rice production in the Republic of North Macedonia.

In 2014 the sowing was done on 25 April and in the second experimental year (2015) on 07 May. Standard agro-technological practices were applied. In 2014, from 19th September until 11th October and from 21th September to 12th October in 2015, representative samples with moisture content between 20-22% (I variant), 18-20% (II variant) and 16-18% (III variant) were taken manually from each variety and repetition. After the harvest, the grain was separated from the straw by hand. A standard oven method was applied to determine the average moisture content. After the drying finished, the samples were left at room temperature to achieve grain moisture content between 13% and 14%. Using laboratory Paddy quality test machine – CRM 125 2T (1.5min), 50g of paddy from each sample were processed into white rice. Milled rice yield and broken kernels separately were calculated in percentages.

Milled rice yield and broken kernels were estimated by years and varieties using JMP 5.0.1 program. Fit analysis was performed to obtain the least significant differences (LSD values) for the tested varieties by years. Based on the LSD data, the varieties were grouped and the varieties with the highest values of the studied traits belong to group a. In order to evaluate the relationship between the percentage of milled rice yield and broken kernels, Principal Component Analysis (PCA) was performed by Statgrap 2.1.

Results and discussion

In Table 1 are presented the mean values for milled rice yield and broken kernels by variety and by year. In the first testing year (2014) the varieties Arsenal, Sprint, Ulisse, Mirko, Gloria, Creso, Vasko and San Andrea achieved higher average values for milled rice yield compared with the second experimental year. The other varieties (Nembo, Ronaldo, Galileo, Krystalino, Sfera and Pato) showed higher mean values for milled rice yield in the second year of study. In 2014, the highest percentage for milled rice yield was obtained from Gloria variety (71.05%) and the lowest from Galileo (50.36%). San Andrea also scored high percentage for milled rice yield (70.36%). In the second experimental year, the highest percentage of milled rice yield was achieved from Arsenal (68.30%), followed by Ronaldo (68.26%). From all analyzed varieties, Ulisse showed the lowest milled rice yield (60.13%). In this year of testing, the standard variety San Andrea was also among the varieties with higher milled rice yield. Except Arsenal, Ronaldo, Sprint and Mirko, all other varieties showed lower average percentage for milled rice yield compared with the mean value obtained from San Andrea variety. The mean value for milled rice yield for all tested varieties in 2014 did not significantly differ from the average value obtained in 2015 (64.62% in 2014 and 64.31% in 2015, respectively). The average percentage of milled rice yield for all tested varieties during the period of study was 64.47%. San Andrea, Arsenal, Sprint and Mirko made the highest average percentage for milled rice yield during the period of study (Table 1).

Table 1. Mean values for milled rice yield (%) and broken kernels (%) by variety and year

Variety	Mean values for milled rice yield (%) by variety and year			Mean values for broken kernels (%) by variety and year		
	2014	2015	2014-2015	2014	2015	2014-2015
Arsenal	69.17^{c}	68.30^{a}	68.74	9.75^{f}	9.24^{e}	9.50
Nembo	62.07^{h}	62.93^{f}	62.50	10.05^{d}	12.02^{i}	11.04
Ronaldo	67.43^{e}	68.26^{a}	67.85	10.39^{f}	7.75^{c}	9.07
Galileo	50.36^{k}	60.20^{j}	55.28	13.31^{hi}	15.40^{j}	14.36
Sprint	68.64^{cd}	67.87^{b}	68.26	8.64^{ab}	6.66^{b}	7.65
Ulisse	64.77^{g}	60.13^{k}	62.45	13.57^{i}	16.23^{k}	14.90
Krystalino	55.57^{j}	61.76^{h}	58.67	8.44^{a}	8.74^{d}	8.59
Mirko	68.61^{d}	67.85^{b}	68.23	8.82^{gh}	6.33^{a}	7.58
Sfera	61.76^{h}	62.05^{h}	61.91	9.70^{cd}	11.48^{h}	10.59
Gloria	71.05^{a}	61.20^{i}	66.13	10.48^{g}	12.04^{i}	11.26
Pato	60.99^{i}	63.76^{e}	62.38	9.02^{c}	9.11^{e}	9.07
Creso	66.81^{f}	66.21^{d}	66.51	10.15^{e}	10.63^{g}	10.39
Vasco	67.14^{ef}	62.33^{g}	67.74	10.71^{gh}	8.67^{d}	9.69
San Andrea	70.36^{b}	67.49^{c}	68.93	10.37^{f}	10.31^{f}	10.34
Mean	64.62	64.31	64.47	10.24	10.33	10.29
$LSD_{0.05}$	0.54	0.28		0.28	0.22	

*Mean values in each column followed by the same later are not significantly different P<0.05

In 2014, Krystalino had the least broken kernels (8.44%) and in the second testing year it was variety Mirko (6.33%). Ulisse variety showed the most broken kernels in both years of research (13.57% and 16.23%, respectively). The average percentage for broken kernels for all tested varieties during the period of research was 10.29%. No statistical differences were recorded in mean percentages for broken kernels for all tested varieties in 2014 and 2015 (10.24% and 10.33%, consequently). Mirko showed the least average percentage for broken kernels (7.58%), followed by Sprint (7.65%) from all tested varieties, during the period of study (Table 1).

In order to obtain maximum rice yield and total milled rice it is essential rice to be sown and harvested just on time. Early harvesting may reduce the field yield of paddy and head rice yield due to presence of immature kernels. On the other hand, the late harvesting may also reduce the rice yield because of grain shattering and lodging. The crop should be ready to harvest when 80% of the panicles are straw - colored and the grains in the lower portions of panicle are in the hard – dough stage.

Table 2 presents the data for average, minimum and maximum values for milled rice yield and broken kernels by variants, as well as their variation based on moisture content during the harvest time. The highest average percentage for milled rice yield was obtained by the III variant (grain moisture content varied from 16% to 18% during the harvest). Also, the percentage of broken kernels was the highest from the III harvesting variant (12.79%). Actually, the percentage of broken kernels was the smallest (7.96%) when moisture content during the harvest time had the highest value (I variant) and gradually increased with fall of the moisture content (Table 2).

Table 2. Average, minimum and maximum values for milled rice yield (%) and broken kernels (%) by variants

Variants (harvest time)	Mean values for milled rice yield (%) by variants			Mean values for broken kernels (%) by variants		
	I variant (20-22%*)	II variant (18-20%)	III variant (16-18%)	I variant (20-22%)	II variant (18-20%)	III variant (16-18%)
Average	64.19	64.33	65.23	7.96	10.11	12.79
Min	55.94	53.60	57.54	5.26	7.25	9.46
Max	70.84	70.35	69.04	10.49	10.97	19.80
CV, %	6.17	7.36	5.45	19.77	19.90	23.23

*Moisture content; CV, % = Coefficient of variation

In India, Grovindaswami and Ghosh (1968) had reported that harvesting between 27 and 39 days after flowering at high moisture content (18% to 20%) gave maximum head rice recovery. Harvesting before and after that period results in increase of broken kernels. The same results were obtained in our study. From our research, milled rice yield showed the highest value when the moisture content during the harvest time was from 16% to 18%. In California, some rice growers reported high rice yields harvesting at 22% to 26% moisture, while in Arkansas, rice is harvested at 18% to 22% moisture content (Huey, 1977). The effect of harvest time on milled rice yield and broken kernels in rice varieties had been studied by many authors. Ntanos et al. (1996) reported the highest average milled rice yield when the paddy was harvested with average moisture content of 17.9% and the lowest milled rice yield - with 22.2% average moisture content. The percentage of broken kernels was the highest in harvest with an average moisture content of 13.9% and the lowest when the paddy was harvested with 17.9% average moisture content. According to Siebenmorgen et al. (2006), the general range of optimal harvest moisture contents, determined as the moisture content at which head rice yield peaked, varied from 19% to 22% for long-grain cultivars and from 22% to 24% for medium grain Benga. Bautista et al. (2009) reported that the optimal harvest moisture content for long-grain cultivars generally ranged from 18% to 22% and 19% to 20% for medium-grain cultivars. Similar results of those have been reported by Bautista and Siebenmorgen (2008). According to Siebenmorgen et al. (1992), the optimum harvest moisture content for maximum head rice yield ranged from 18% to 26%, based on growing location, harvest date and cultivar. Ilieva et al. (2009) found the highest milled rice yield (64.54%) when the moisture content in grain was between 18% and 20%. In all tested rice varieties, there was significantly lower milled rice yield when the paddy was harvested with moisture content over 20% and below 18%.

Principal Component Analysis (PCA) is one of the most important multivariate methods (Oyelola, 2004). PCA has been used by various workers like Maji and Shaibu (2012), Gana et al. (2013) and Kumar et al. (2015) for characterization of different rice varieties and traits.

In order to evaluate the relationship between the percentage of milled rice yield and broken kernels, PCA was performed. Using PCA, three main components have been extracted with eigen value higher than 1. The cumulative percentage of those three components was 91.44% (Table 3). According to Pachauri et al. (2017) PCA exhibited more than 1 eigen value and showed about 72.48% cumulative variability among the studied traits. The factor weights of main components associated with analyzed traits (percentage of milled rice yield, percentage of broken kernels and moisture content during the harvest) by the principal component axis are given in Table 3. The first main component was highly positive associated with the percentage of milled rice yield and moisture content from I, II and III harvest variants. The second main component was responsible for varying the percentage of broken kernels and moisture content. PC3 showed high positive value by moisture content of the III harvest variant.

Table 3. Eigen value, percentage of variation and factor weights of tested traits by the principal component axes

Parameters	PC1	PC2	PC3
Eigen value	4.77	2.13	1.34
Percentage of variance (%)	52.95	23.62	14.88
Cumulative percentage (%)	52.95	76.57	91.44
Traits/Variant		Factor weights of tested traits	
Milled rice yield – I variant	0.39	0.08	-0.32
Broken kernels – I variant	-0.33	0.43	-0.11
Moisture content – I variant	0.27	0.48	-0.04
Milled rice yield – II variant	0.43	0.10	-0.24
Broken kernels – II variant	-0.35	0.39	-0.21
Moisture content – II variant	0.24	0.49	0.28
Milled rice yield – III variant	0.42	0.13	-0.21
Broken kernels – III variant	-0.36	0.31	-0.34
Moisture content - III variant	0.04	0.26	0.73

The variety strongly influenced milled rice yield and broken kernels, but in order to obtain a higher grain yield and less broken kernels, the harvest time, expressed as grain moisture content, is an important factor. Therefore, we also included moisture content as a factor in milled rice yield and broken kernels variation as expressed by PCA.

Figure 1 presents the distribution of examined rice varieties by tested traits and variants. The distribution of those variants in factor space indicates that higher yield can be expected when moisture content during the harvest ranges from 18% to 20% or from 16% to 18%. The position of Ronaldo and Vasco varieties between the vectors of moisture content from II and III variant indicate that the percentage of milled rice yield is strongly dependent on moisture content during the harvest time and beside the impact of variety and environmental conditions, moisture content is an important factor and determinates the harvest time. Those varieties have high values for milled rice yield and low percentages for broken kernels. The varieties Mirko, Sprint, Arsenal and Creso are located close to the vectors of milled rice yield from all variants, which shows that the percentage of rice yield is rather genetically determined and rarely influenced by conditions of the year.

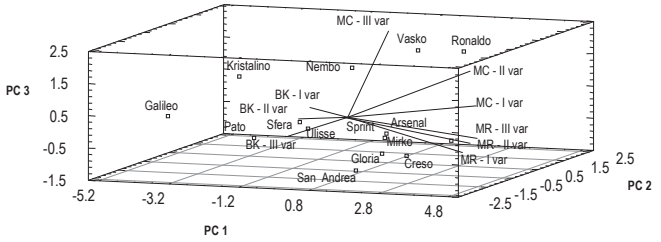

Figure 1. Distribution of tested rice varieties and traits in factorial space

(MC= moisture content; MR= milled rice yield; BK= broken kernels; var= variant)

Conclusion

Based on the results obtained, it was found that higher percentage of milled rice yield can be achieved when moisture content during the harvest time ranged from 18% to 20%. The varieties Arsenal, Sprint and Mirko had the most favorable values for milled rice yield and broken kernels. Ronaldo and Vasco varieties also showed high values for milled rice yield, which depend heavily on moisture content during the harvest.

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