

Plant productivity parameters in rice varieties with different type of panicles and their variability

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Abstract. To increase rice yield, scientists are considering the possibility of changing the morphological parameters of plants. At the same time, there are not enough attempts in Russia to analyze the yield potential of varieties with different panicle architectonics. The purpose of our research was a comparative analysis of rice varieties differing in panicle morphotype, by the formation of productivity elements. In the ecological conditions of the south of Russia, in 2019-2020, a series of field experiments were carried out with 24 *Oryza sativa* L. varieties under conditions of artificial irrigation. The results of assessing the elements of plant productivity and biological productivity of varieties differentiated into 6 groups according to the panicle type and grown on plots 1x12 m are presented. The present study showed that in the rice-growing zone of Krasnodar region, varieties with a compact inclined and slightly spreading panicle had an advantage in achieving high productivity. However, the stability of quantitative traits was exhibited by varieties with spreading panicles of the drooping type. Correlation analysis confirmed: the longer the panicle, the more spreading it is and the less sterile spikelets are formed on it. Along with other researchers, we revealed significant differences in yield between *japonica* and *Indica* varieties. Due to the cultivation of varieties under equal conditions, the variation in biological yield from 778 to 1203 g / m² can be explained by their genotypic characteristics. For the sustainable development of rice growing in the region, our studies emphasize the importance of the diversity of varieties of various morphotypes with high potential and stability of productivity elements and provide useful information for breeding.

1 Introduction

Achievements in global crop production of food crops have fallen short of expected demographic demand. The breeding of high-yielding, disease-resistant rice varieties with good consumer properties is still relevant today. The climate change scenario over the next 30 years presents a challenge for crop production. Analysis of yield data for a number of crops around the world for the period 1961 - 2008, carried out by American scientists,

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showed that the share of areas where it is not possible to get an increase in yield or it decreases accounts for 24-39% [1].

Rice yield is regulated by both external and genetic factors: growth rate, physiological adaptability, plant architectonics, panicle and grain morphology. Rice science has already made some progress in improving varieties. Scientists in Asian countries have developed a number of varieties with tall erectoid leaves and drooping panicles, the plants of which are more productive in terms of photosynthesis and are resistant to lodging. And during the Green Revolution, varieties with a new plant type "super-rice" of the International Rice Research Institute (IRRI) with an increased yield index, obtained with the involvement of semi-dwarf gene donors and an increased number of spikelets per panicle, became available. However, not in all environmental and climatic conditions, they could realize their potential [2].

The efforts of Russian breeding in recent years are aimed at minimizing the negative effects of climatic stresses that limit the yield and grain quality by selecting adaptable phenotypes, noted by Kharitonov E.M. (2016) and Zelensky G.L. (2019). The increase in rice production is associated not so much with an increase in potential productivity, but with yield stability and complex stress tolerance. Scientists from Primorsky region of the Russian Federation, in search of the parameters necessary to increase the yield of new generation varieties, by comparative analysis came to the conclusion that it is necessary to correct the morphotype of low-growing, intensive type rice varieties for this region. To increase productivity, there is a prospect of an increase in the following morphological and functional characteristics: plant height up to 80-85 cm, yield of aboveground biomass up to 120-140 c / ha, area of 3 upper leaves up to 115-125 cm², level of harvesting index up to 55-57% and medium size of grain. Such new generation rice varieties of various morphotypes are being competitively tested in Primorsky region [3].

In Krasnodar region, in order to develop a resistant variety with a potentially high yield, breeding is being carried out to overcome the negative impact of air drought on rice plants with different types of leaves. An advantage in yield of rice samples YUG-1, YUG-2 and YUG-3 with leaves curled into a tube was revealed due to the low spikelet sterility in these samples under high temperature conditions (2.8%) with the indicator for the standard variety - 14.8 % [4].

The need to increase the productivity of rice varieties around the world has led to the search for the ideal plant architectonics, with the panicle being the key organ in the formation of the rice yield. The North China varietal model with good grain quality and high amylose content was characterized by a wide flag leaf and a second leaf on top, a narrow and short third leaf on top, a short stem, and a large number of spreading panicles. [5].

Breeders consider the type of panicle to be an important component of the plant and a key agronomic important trait of the variety. There are 6 types and 19 subtypes of panicle classification based on the shape and position of the panicle, the number of grains, its length, weight and density. Highly productive varieties of the future are associated with their late maturity and improved panicle genetics, regulation of metabolism in rice to increase the number of spikelets [6, 7]. From a production point of view, Chinese scientists in 2010 suggested that varieties with erect, heavy panicles with a large number of spikelets in secondary branches would be key factors for growing an ultra-high yield of *japonica* rice [8]. In 2014, a field experiment was carried out with 20 rice varieties, belonging to four types, to reveal the difference in yield and its components in the sowing area. Y.H. Jiang, H.C. Zhang et al showed that a large panicle remains the main method of obtaining a high yield of rice [9]. At the same time, for *Oryza sativa*, a correlation of the panicle morphotype with the yield and grain quality was noted [10]. Studies of grain vitreousity of four lines descended from the variety (*O. sativa* L.) Wuyujing 3 with different types of panicles:

compact, intermediate, loose and spreading, showed significant differences in the number of chalky grains between different positions within the panicle for all types of panicles [11]. The culinary and nutritional qualities of varieties with different types of panicles are discussed in foreign literary sources. Thus, *indica-japonica* (*O. sativa* L.) hybrids with a heavy panicle showed a high yield potential, but poor palatability compared to conventional *japonica* rice varieties [12].

The level of technical equipment of modern research makes it possible to predict the yield based on the scanned images of a rice panicle. In 2017, Chinese scientists in Jiangsu province studied the relationship between the attributes of a rice panicle and its weight parameters on 6 varieties. Based on reliable data on the phenotype of agricultural crops, a model has been developed for the rapid assessment of grain yield [13].

Scientific publications discuss that modern high-yielding rice varieties with a very large number of spikelets often have unstable grain filling, and in order to further increase rice yields, an understanding of the factors limiting grain filling is necessary [14]. Studying the yield potential of high-yielding short-grain and long-grain rice varieties, Japanese scientists note the differences: *indica* varieties showed excellent grain filling, while panicle productivity was higher in *japonica* [15]. The panicle architectonics in ecotypes within *O. sativa* L. is characterized by great diversity; such phenotypic diversity is associated with the number of spikelets and the number of branches of different order, and the synchronism of filling. The stability of the manifestation of traits by rice genotypes, as well as the potential yield are important characteristics of the variety, since this crop is sensitive to abiotic stresses [16].

Due to lack of information on the study of this issue in the domestic literature, we started research in order to identify the features of the formation of plant productivity indicators and compare the biological yield in rice varieties of various shapes and panicle densities grown in equal environmental conditions.

2 Materials and methods

A set of rice varieties were grown in the ecological conditions of the southern region of Russia (Krasnodar, p / o Belozerny) under equal conditions of the rice irrigation system of "Federal Scientific Rice Centre" in 2019-2020. Therefore, the factor of the applied technology of rice cultivation (artificial irrigation) was not taken into account when assessing the yield of varieties. In the breeding strategy for the development of more productive varieties, it is necessary to take into account the optimal plant architectonics for a specific ecological-geographical zone. In the experiment, we used 24 varieties of different breeding periods from the USU "Collection of rice genetic resources", differing in the type of panicle.

The size of the experimental plots was 1x12 m, the distance between the plots - 50 cm. The seeding rate was 5 million / ha. Sowing in the field was carried out with a seeder in the first ten days of May. Fertilization of rice crops was carried out with urea in two periods (at the rate of 100 kg per 1 hectare for a.r. or 46 kg of nitrogen per hectare). Treatment with herbicides against marsh weeds was performed two weeks after the emergence of full shoots (Segment, 40 g / ha).

Accounts and observations in the experiment, visual assessments, phenological observations, biometric analysis of plants were carried out according to the "Methods of the All-Russian Rice Research Institute" (1982). The following quantitative traits of rice plants were taken into account: plant height, panicle length, number of branches and total number of spikelets per panicle, percentage of sterile spikelets, panicle density and weight of grain per panicle, grain weight per plant, mass of 1000 grains, biomass of 10 plants (dry biomass with panicles and straw without roots). The selection of sheaves from 10 plants in triplicate

for biometric analysis was carried out in the phase of full ripeness. The biological yield was taken into account by weighing grain, manually threshed from 1 m². The duration of the rice growing season was calculated according to phenology from germination to full grain maturity.

Data processing was carried out in the Statistica 10 program. All quantitative traits presented in the tables are averaged values over two years. For a group of varieties with the same type of panicle, the range of variability of traits (min-max), mean group values, (\bar{x} avg.), standard deviation (SD), and coefficient of variation (CV,%) were calculated. Variability was considered low if its coefficient was less than 10%, moderate if it ranged from 10% to 20%, and high if it exceeded 20%.

Varietal differences in the formation of the elements of plant productivity that affect yield were studied on rice varieties of different ripening periods. By the type of panicle, the varieties were differentiated into 6 groups based on spatial position (on a nine-point scale): 1) compact form, vertical position (1/1 point); 2) compact form, inclined position (1/5 point); 3) weakly spreading form, inclined position (3/5 point); 4) weakly spreading form, drooping position (3/9 point); 5) medium-spreading form, drooping position (5/9 points); 6) spreading form, drooping position (7/9 points).

3 Results and discussion

Rice collection in the "Federal Scientific Rice Centre" has more than 7.3 thousand samples of *O. sativa* L., of two subspecies *indica* and *japonica* from 42 countries of the world and is characterized by a wide variety of rice forms [17]. In the studied set of varieties, their panicles clearly differed in architectonics, length and density; for each morphotype, 3-6 varieties were selected, adapted to the ecological conditions of the region. Both domestic and foreign rice varieties with the duration from 95 to 128 days were taken into the experiment. Genotypes of different ripening periods are included in each group for objective comparison of the average group parameters of plant productivity.

Table 1 shows the averaged characteristics of the studied varieties over the years of research, differentiated into groups according to panicle type. In terms of plant height, the studied varieties are mainly assigned to the group of medium-sized (from 80 to 110 cm), only the variety Taibonne is classified as low-growing, and Anait, Fisht, Marzhan and Avstral formed plants of a transitional morphotype from medium-sized to tall. The ratio of panicle length to plant height in the studied varieties varied within 0.15-0.18. Evaluation of correlations of plant height with other vegetative traits showed an average value of its positive conjugation ($r = 0.47$) with the panicle length and the length of the flag leaf ($r = 0.41$). The panicle length by varieties reached a value from 14.5 cm to 20.3 cm, and in the group of plants with spreading panicles it significantly exceeded the genotypes with compact panicles.

In the tested genotypes with compact panicles, a greater number of primary branches per panicle was observed, while that of the secondary ones was approximately the same and varied from 6 to 10 pcs. Rice varieties with a compact panicle with a density higher than 7.0 pieces / cm formed smaller caryopses with a "mass of 1000 grains" on average 25-26 grams, on weakly spreading panicles the grain size reached 29-37 grams. The group of varieties with erect dense panicles formed increased productivity due to a greater number of spikelets, and genotypes with poorly spreading ones - due to the filling of larger grains. The data in the table show that the productivity of plants of all varieties is quite good - within 3.11-5.02 g.

Table 1. Characteristics of rice varieties of six groups with different panicle types by biological, morphological traits of plants and yield, average for 2019-2020.

Variety	Durati on, days	Plant height, cm	Panicle length, cm	Total number of panicle branches, pcs.	Mass of grain per plant, g	Biological grain yield per plot, g/m ²	Mass of 1000 grains, g
compact vertical (1/1)							
Atlant	122	93-105	15,26	25	4,12	1030±16	27,8
Liman	110	90-98	16,94	17	4,80	1200±22	26,3
Khazar	118	87-95	14,53	25	3,39	848±76	25,2
Yubileyny 85	105	80-87	15,64	19	3,86	965±34	28,5
Olimp	122	95-107	16,10	20	4,02	1005±26	27,0
Diamant	107	85-92	15,10	18	3,55	887±41	25,2
<i>mean value</i>	<i>114</i>		<i>15,59</i>	<i>20,66</i>	<i>3,95</i>	<i>989,16</i>	<i>26,66</i>
compact inclined (1/5)							
Victoria	105	97-103	14,87	21	4,81	1203±12	28,0
Novator	98	88-95	16,61	19	4,45	1112±29	24,6
Leader	123	93-100	14,47	19	3,46	865±55	26,9
Flagman	115	82-90	15,10	21	4,20	1050±21	26,1
<i>mean value</i>	<i>110</i>		<i>15,26</i>	<i>20,0</i>	<i>4,23</i>	<i>1057,5</i>	<i>26,40</i>
weakly-spreading inclined (3/5)							
Regul	116	95-100	16,40	21	3,88	970±18	28,4
Yantar	115	90-97	15,69	22	3,87	968±16	32,0
Anait	98	107-113	19,54	19	5,04	1260±12	37,8
Favorit	112	95-100	15,23	21	4,67	1167±24	30,8
<i>mean value</i>	<i>110</i>		<i>16,71</i>	<i>20,75</i>	<i>4,36</i>	<i>1091,3</i>	<i>32,25</i>
weakly-spreading drooping (3/9)							
Aral 22	100	95-100	16,89	18	4,40	1100±12	31,1
Krepysh	120	87-95	15,36	15	3,61	903±38	34,2
Yuzhanin	107	98-103	18,66	23	4,30	1075±9	26,8
<i>mean value</i>	<i>109</i>		<i>16,97</i>	<i>18,66</i>	<i>4,10</i>	<i>1026,0</i>	<i>30,70</i>
medium-spreading drooping (5/9)							
Baldo	117	97-105	14,97	17	4,45	1112±29	35,7
Fisht	112	107-112	20,25	19	5,02	1250±17	22,5
Taibonne	128	70-85	16,50	15	3,11	778±54	24,3
Marzhan	100	109-120	17,34	15	3,27	817±11	30,7
<i>mean value</i>	<i>114</i>		<i>17,26</i>	<i>16,5</i>	<i>3,96</i>	<i>989,25</i>	<i>28,30</i>
spreading drooping (7/9)							
Avstral	112	107-112	18,39	18	3,86	965±28	23,8
Snezhinka	122	92-98	17,01	19	3,51	877±26	22,7
Sharm	95	83-90	19,01	18	3,68	920±32	24,3
<i>mean value</i>	<i>109</i>		<i>18,13</i>	<i>18,3</i>	<i>3,68</i>	<i>920,66</i>	<i>23,60</i>
LSD ₀₅			0,47		0,21	46,2	

The calculation of the average group values of the biological grain yield from the plot showed us that the highest yield per square meter was formed by *japonica* rice varieties with a compact inclined and weakly-spreading inclined panicle of 1057.5 and 1091.3 g / m², respectively. The genotypes of *japonica* with a compact erect panicle were significantly inferior to them in terms of yield (989.1 g / m²), and the lowest indicator, on average for two years of research, was obtained in long-grain *indica* varieties with a drooping, spreading panicle: Taibonne, Austral and Snezhinka (778- 965 g / m²). However,

genotypic variety-specificity in the formation of high biological yield was revealed in each presented group of varieties according to the panicle type. The varieties with the best productivity indicators in the experiment were selected: Liman, Victoria, Novator, Anait, Favorit, Aral 22, Baldo and Fisht.

The conjugation of the panicle morphotype and its structural elements with other quantitative traits for the set of varieties under study, based on the correlation analysis, indicates that the longer the panicle, the more spreading it is and less sterile spikelets are formed on it. The panicle shape and its position negatively correlated with the spikelet sterility ($r = -0.39$ and -0.44 , respectively). The value of "grain mass per panicle" showed a weak negative relationship with the position of the panicle ($r = -0.29$), its length ($r = -0.28$) and positive with the compactness of its shape ($r = 0.32$). The highest grain density is formed by plants with compact vertical and inclined panicles. A weak negative conjugation of the panicle type was noted with the duration ($r = -0.18$) and medium - with the "total number of spikelets" per panicle ($r = -0.36$). The results of the correlation analysis confirm the data of the analysis of the average group indicators of varieties by panicle types, presented in Table 2.

Table 2. Average group indicators of productivity elements of rice varieties and their variability for different panicle morphotypes, (2019-2020)

Panicle type	Panicle length, cm		Total number of spikelets on panicle, pcs		Grain sterility, %		Panicle density, pcs/cm		Mass of grain per panicle, g	
	min-max	\bar{X}	min-max	\bar{X}	min-max	\bar{X}	min-max	\bar{X}	min-max	\bar{X}
1/1	14,5-16,9	15,6	101,6-197,0	137,3	11,5-31,2	18,5	6,5-11,6	8,7	2,1-3,6	2,8
1/5	14,5-16,6	15,2	101,0-135,8	123,8	9,4-15,3	12,2	6,8-8,7	7,9	2,4-3,3	2,9
3/5	15,2-19,5	16,7	99,1-112,0	104,4	12,1-23,3	17,5	5,5-6,7	6,2	2,4-3,4	2,7
3/9	15,4-18,7	16,9	79,7-160,5	112,3	11,6-24,2	16,0	5,2-8,5	6,5	2,1-3,9	2,9
5/9	14,9 - 20,3	17,3	70,6-113,3	85,9	8,7-17,9	13,1	3,9-5,5	4,9	1,6-3,3	2,3
7/9	17,0-19,1	18,1	85,3-136,7	106,0	11,2-15,1	13,4	4,5-7,5	5,9	1,9-2,8	2,2

The variability of the average values of the "total number of spikelets" on a panicle was within 70.6-197 pieces, the percentage of sterile grains was within the range of 8.7-31.2, and the panicle density was 3.9-11.6 pieces / cm, grain mass per panicle - 1.6-3.9 g. The maximum average group number of spikelets per panicle in varieties with a compact panicle (137.3 pcs.), is reliably inferior in this trait to varieties with a spreading drooping panicle (85.9 pcs.). The maximum percentage of sterile spikelets (17.5-18.5%) was noted for groups of varieties with a compact and weakly spreading panicle with a spikelet density in the range of 7.99-8.67 pcs / cm. The drooping panicle in rice is often loose, but with a smaller number of empty grains, by almost 5%. The grain mass per panicle (2.9 g) is higher in groups of varieties with a compact inclined and weakly spreading drooping panicle. Our studies have shown that the denser the panicle is, the smaller the grains formed on it. In a number of varieties with compact panicles, the obtaining of potentially high plant productivity is hindered by poorly filled spikelets in the lower parts of the panicle. Our data are consistent with the experimental data of Tilak Chandra (2021), who notes that the development of caryopses at the stage of filling is associated with their spatial position on a compact panicle and the intensity of biochemical and physiological processes [18]. The

average group value of a trait summarizes its quantitative value for varieties, and the coefficient of variation shows in percent the variability of a trait for the genotypes of a given sample. Table 3 shows the average results of variability of productivity elements in groups of varieties differing in the panicle type over the years of research.

Table 3. Coefficients of variation of productivity traits of rice varieties in groups with different panicle morphotypes (CV,%)

Panicle type	Panicle length		Total number of spikelets per panicle		Grain sterility		Panicle density		Mass of grain per panicle	
	min-max	\bar{X}	min-max	\bar{X}	min-max	\bar{X}	min-max	\bar{X}	min-max	\bar{X}
1/1	2,4-12,2	7,3	9,6-40,0	24,6	25,0-41,7	35,0	8,2-30,8	20,8	16,1-39,9	28,8
1/5	8,6-12,4	11,1	25,3-38,0	30,3	18,8-44,8	30,3	16,5-28,7	22,2	28,8-39,7	33,5
3/5	6,5-14,7	10,2	27,1-35,2	30,5	5,2-37,5	26,5	21,4-26,3	23,8	24,6-46,1	34,7
3/9	7,0-11,9	9,4	15,3-24,7	21,3	26,2-44,8	32,9	9,6-17,0	14,1	12,7-29,4	21,9
5/9	10,2-13,6	12,1	28,9-41,6	34,2	30,1-37,2	32,9	20,5-33,7	26,8	26,2-45,4	36,7
7/9	6,9-8,2	7,7	16,9-20,9	18,9	25,2-35,9	29,6	12,2-18,8	14,9	18,3-22,4	20,2

As can be seen from the table, the variability of the panicle length trait is in the range of 2.4-14.7%. High coefficients of variation were noted for the traits "total number of spikelets" - 9.6-41.6%, "grain sterility" - 5.2-44.8%, "mass of grain per panicle" - 12.7-45.4%. At the same time, the average group coefficient of variation of the trait "mass of 1000 grains", which is considered the most genotypically stable trait, was higher in the group of varieties with a compact panicle (5.2-7.5%), i.e. these genotypes are less resistant to external environmental factors during the grain filling phase. An insignificant variability in grain size was noted in the group of varieties with a spreading panicle (4.9%), a similar pattern was observed for other elements of panicle productivity. The smallest variability of the "panicle length" trait was observed in varieties with a compact vertical panicle (7.31%), and the traits "total number of spikelets" (18.9%), "panicle density" (14.1%), "mass of grain per panicle" (20.2%) - in varieties with a spreading drooping panicle. Genotypic heterogeneity and high variation were noted for the "grain sterility" trait. We found that genotypes with a spreading type of panicle are the most stable in the formation of plant productivity according to the growing seasons, although the absolute value of their productivity is inferior to varieties with a compact dense panicle.

The calculation of the absolute values of the coefficients of variation for each individual variety made it possible to isolate genotypes with more stable traits (CV <10%) under the weather and climatic conditions of 2019 and 2020. In our experiment, these are varieties with different types of panicles: the spreading drooping Austral, Sharm and Snezhinka; weakly spreading Krepys and Yuzhanin; compact inclined Victoria and Flagman; compact vertical Olymp and Atlant. At the same time, high variability of traits (CV > 30%) was revealed in varieties of foreign breeding with a medium-spreading panicle Marzhan, Taibonne and Baldo; inclined Favorit, Anait, Regul; compact vertical Diamant.

4 Conclusions

In a comparative study of the elements of productivity and yield of rice varieties with six panicle types, we observed the following differences: rice plants with compact dense panicles formed increased productivity due to a larger number of spikelets, and genotypes with a spreading type - due to the filling of larger grains. The heaviest panicles and the value of the biological yield per square meter were formed by varieties with panicles of inclined and weakly-spreading drooping type. The genotypes of *japonica* rice with a compact vertical panicle were significantly inferior to them in terms of yield, and the lowest biological yield on average in two years was obtained in long-grain *indica* varieties with a drooping, spreading panicle.

There was no significant difference in productivity between varieties with inclined panicles of compact and weakly spreading forms, however, a high coefficient of variation indicates instability in the formation of productivity in these genotypes. At the same time, we demonstrated that the spreading drooping panicle type is less subject to variability. And with the help of correlation analysis, we were able to establish an inverse correlation of the panicle length with the spikelets sterility. A high potential for plant productivity, along with a tendency towards high variability of its elements, was observed in varieties with dense compact panicles.

Comparison of yields and variability coefficients for traits of a wide range of rice provided us with important information for breeding and sustainable grain production. In the southern region of Russia, subject to the technology of cultivation and the water regime, it is possible to obtain high yields using varieties of different panicle morphotypes. The most stable and productive are: Avstral with a spreading drooping panicle, weakly spreading Yuzhanin; compact inclined Victoria and Flagman, compact vertical Olymp and Atlant.

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