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Research Article

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Formation of Grain of Intensive and Extensive Rice Varieties

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ABSTRACT

The present article contains the results of the study on the grain filling process of five different rice varieties. It was established that the amount of the carbohydrates stored in the stems before the flowering of plants had a close connection with a thousand kernels weight (TKW). During the ripening period of rice, these compounds are intensively used for kernel filling; the level of their mobilization is up to 80-96 %. The reduced provision of the developing kernels with metabolites in the intensive varieties is shown. It is associated with their number on a panicle, which affected the TKW, wherein the reserve of carbohydrates in the weight of kernels was 8.9-13.0% in the intensive varieties, and 15.5-17.1% - in the extensive ones. The intake of stored and current assimilates by the kernels of extensive varieties was by 19.6-21.6 % higher than in the intensive genotypes, which is shown by their mass per 100 kernels. TKW has a positive correlation with the values of these features, which can characterize the types of varieties (intensive or extensive).

Key words: rice varieties, assimilates, carbohydrates, thousand kernel weight (TKW), grain filling

INTRODUCTION.

The main reason for the increase in productivity of modern agricultural varieties during their genetic improvement is not the enhancement of photosynthetic apparatus functioning, but the alterations in the system of distribution of assimilates in the plant organs that leads to the increase of the grain weigh in its total biomass [1-4]. Hence, these processes of formation, transport, consumption, and storage of nutrients according to the demands of the plant organs are in focus of the researchers' interest. The most crucial stage of the ontogenesis of rice is the period of filling when the metabolism of all the plant organs is switched to the provision of the developing kernels with the required plastic material. The intensity of these processes is

reflected by TKW of a given variety. The decrease in TKW indicates the insufficient provision of the developing kernels with the metabolites. This insufficiency is caused by the unfavorable growing conditions, including increased content of nitrogen in the soil [5, 6]. It was established that different yielding of rice varieties is primarily defined by the nonuniform productivity of panicles associated with different grain setting and their absolute weight (TKW). High-yielding panicles of rice are formed by the genetic program of their growth and development when the metabolism of a plant is closely related to the provision of panicles with carbohydrate and nitrogen metabolites. Their intensive transport to the panicle is defined by its attracting activity that is regulated by the hormones and grain setting [7, 8]. The main compounds consumed during the grain filling are the deposits of carbohydrates in vegetative organs and assimilates of the plants photosynthesis during the period of grain formation [6]. High yield and good quality of grain are formed in the conditions of optimum provision of the developing grain with the initial metabolites. The studies on the grain filling showed significant differences in this process in the intensive and extensive varieties of rice, which affected their yield and grain quality. The formation of the high-yielding crop varieties, including rice, is associated with a more effective utilization of the assimilates of the photosynthesis and accumulated nutrients [6, 9, 10]. It was shown that the intensive and extensive varieties of rice differ by the accumulation and level of mobilization of plastic substance during the grain filling. This affects the TKW and the yield of these genotypes. However, the qualitative parameters of the formation and utilization of the assimilates, characterized as donor-acceptor relations, are understudied in these varieties. Hence, our task was to study these parameters that are important for the evaluation of the selection samples for the grain quality and productivity.

The aim of the present study was to investigate the provision of the filling grain of the intensive and extensive varieties of rice with the accumulated carbohydrates and assimilates of the photosynthesis that affects the TKW.

MATERIALS AND METHODS.

The studies on the formation of rice were conducted during the period from 2012-2015. It is important to choose of materials close to the principle of the single difference. Hence, the authors chose the varieties with a similar length of vegetation period – Rapan, Visit, Gamma (intensive) and Sonata, Atlant (extensive). The trials were set in concrete tanks that allowed the authors to maintain the irrigation plan similar to the field conditions [11, 12]. The area of a tank was 3.6 m^2, it was filled with meadow black soil taken from the rice irrigation system of the ARRRI. Different fertilization plans were used because the productivity and resistance of the genotypes to logging and unfavorable environmental factors are closely related to their reactions to the level of the plants provision with microelements. Fertilization plans were $N_{12}P_6K_6$ (medium), $N_{24}P_{12}K_{12}$ (optimum) and $N_{36}P_{18}K_{18}$ (high) g of active ingredient per 1 m^2. The density of the plantstand was 300 plants/m^2. The trial plots areas were 1.2 m^2. The tests were conducted in triple replication. The seeds were planted in lysimeter sections, which provided the even distribution of plants. They were planted at low (0.5 cm) and even depth. When the seeds germinated, their thinning was performed, which reduced the non-uniformity of plants. During the vegetation period, a reduced plan of the irrigation was maintained. The rice germinated on moist soil that was flooded 2-3 cm high during the phase of 1-2 true leaves, the level of water was raised to 7-8 cm as the plants were growing and maintained at this level to the end of ripening of rice.

The samples of plants were taken based on the vegetation phase so that their morphological parameters were close to the mean values of the studied features of all the plants of the tested variety.

The authors chose averagely developed plants; their weight was close to the mean values of all the plants in the sample. Such plants were identified by the average level of the total and productive tillering observed in the majority of

plants of each variety. The samples of plants taken during the phases of flowering and full ripeness were used for the estimation of the weight of the stem and panicles, the content of accumulated carbohydrates, TKW (absolute dryness) [11], panicle weight gain during the period of flowering and full ripeness. The obtained data were processed by the methods of biometrical statistics [13].

It should be noted that the study of physiological peculiarities of different varieties of rice and their evaluation directly by the physiological features that are dynamic and changing in the process of ontogenesis is quite complicated. However, they affect the final metabolism results, primarily, carbohydrates and proteins content, and the formation of certain vegetative and reproductive organs. Identification of their parameters and establishment of their correlations with the yield and elements of its structure provides the data on the morphological features that can be used for the evaluation of the selection forms of rice for the productivity and resistance to abiotic factors. These approaches and methods allowed the authors to identify the main peculiarities of the production process of rice varieties that determine the morphological features of plants and can be used for the development of a model of an intensive genotype of rice [6].

RESULTS.

One of the main sources of nutrition of rice kernels are non-structural carbohydrates (NSC) accumulated in stems (in straw and sheaths) in a form of starch and saccharose during the period of shooting and flowering and beginning of grain filling.

The data on their content in the phase of flowering and their correlation with the TKW in five varieties grown under different fertilization plans are shown in Table 1.

Table 1. The content of NSC in the stems of plants in the phase of flowering, the level of their reutilization during the period of filling and its correlation with TKW of the rice varieties.

Variety	TKW, absolutely dry, g	Content of NSC during the phase of flowering		The level of NSC reutilization	
		%	mg/stem	mg/stem	% of the total content
Fertilization plan – $N_{12}P_6K_6$ (1)					
Rapan	21.78	28.13	645.70	588.00	91.06
Visit	21.40	25.30	541.03	518.63	95.86
Gamma	22.26	26.73	590.7	560.7	94.9
Sonata	24.97	25.24	538.63	388.63	72.15
Atlant	23.39	28.40	678.29	564.39	83.21
Correlation coefficient with TKW		–	–	-0.73± 0.24	-0.96± 0.15
Fertilization plan – $N_{24}P_{12}K_{12}$ (2)					
Rapan	20.57	20.48	322.47	289.47	89.77
Visit	20.95	18.09	265.97	236.37	88.87
Gamma	20.84	16.29	218.1	196.6	90.1
Sonata	23.72	27.06	436.13	352.03	80.72
Atlant	22.76	23.88	456.50	268.50	58.82
Correlation coefficient with TKW		0.91± 0.24	0.85± 0.19	0.71± 0.25	0.59± 0.22
Fertilization plan – $N_{36}P_{18}K_{18}$ (3)					
Rapan	19.53	16.99	263.97	200.47	75.94
Visit	19.93	13.82	218.10	163.90	75.15
Gamma	19.39	8.23	103.0	52.6	51.1
Sonata	22.66	18.85	320.63	199.03	62.07
Atlant	22.37	16.23	335.40	140.80	41.98
Correlation coefficient with TKW		0.64± 0.21	0.79± 0.21	–	–
LSD_{05} var.		–	8.44	15.60	–

The content of NSC in stems primarily depends on the level of nitrogen in the soil. Their highest relative and absolute contents are observed when the plants are grown under average fertilization plan ($N_{12}P_6K_6$), wherein it is equal to 25-28% or 541-678 mg per stem. The content decreases due to the increase in density which results from the enhanced tillering of plants. This happens under the influence of the increased doses of mineral fertilizers that result in the reduction of pure productivity of photosynthesis, as well as the increased consumption of the assimilates for the maintenance of the vegetative organs enriched with the protein structures and metabolization of ammonia nitrogen that is absorbed by the root system in great amounts.

Varietal differences are clearly observed by both relative and absolute content of NSC in stems. The extensive varieties Sonata and Atlanta accumulated more carbohydrates than the intensive varieties Rapan, Visit and Gamma grown in the conditions of all the tested fertilization plans.

Carbohydrates accumulated in the plants stems before the flowering are important for proper grain filling. This is proved by a high direct correlation ($r = 0.64 \pm 0.21 - 0.91 \pm 0.14$) between their content and TKW. During the period of rice ripening, these compounds are used for the kernels filling. The level of carbohydrates mobilization is up to 80-96% and the values of the reutilized substances contained in the stem closely correlate with TKW ($r = 0.71 \pm 0.25$).

In the conditions of high nitrogen content in the soil, Gamma and Atlant varieties had the share of mobilized carbohydrates in the stem reduced because of a negative influence of nitrogen.

However, the main sources of the plastic substances that are utilized for the kernels filling are the products of the photosynthesis of the leaves during the phase of plants ripening. Part of these assimilates are spent for the maintenance of the gas exchange in the vegetative organs, but primarily, they are transported to the main attracting center (a panicle), where it is used for starch and protein synthesis in kernels [5]. The data on the sources of nutrition for the panicles in rice and their correlations with the absolute weight of kernels are presented in Table 2.

Table 2. TKW in intensive and expensive varieties of rice and its correlation with the values of grain filling sources under different fertilization plans (2012-2015)

Variety	TKW, g	Weight gain, g/panicle			Per 100 kernels, g
		NSC in a panicle during the period of filling	Panicle during the period of filling	Sum of these sources	
Fertilization plan – $N_{24}P_{12}K_{12}$					
Rapan	20.57	0.29	1.83	2.12	2.24
Visit	20.95	0.24	1.57	1.84	2.26
Gamma	20.84	0.20	1.60	1.80	2.24
Sonata	23.72	0.35	1.45	1.80	2.81
Atlant	22.73	0.27	1.55	1.82	2.56
Correlation with TKW		–	-0.74± 0.19	–	0.99± 0.08
Fertilization plan – $N_{36}P_{18}K_{18}$					
Rapan	19.53	0.20	1.53	1.73	1.98
Visit	20.95	0.16	1.34	1.50	2.12
Gamma	19.39	0.05	1.46	1.51	2.02
Sonata	22.66	0.19	1.27	1.46	2.43
Atlant	22.37	0.27	1.23	1.50	2.54
Correlation with TKW		–	-0.95± 0.14	-0.60± 0.28	0.95± 0.18
LSD_{05} var.	0.17	–	0.03	0.04	0.04

The weight of the reutilized substances contained in the stem differs considerably between the studied varieties of rice during the period of kernels filling in the conditions of optimum and high fertilization. In the extensive varieties Sonata and Atlanta, they are higher than in the intensive varieties Rapan, Visit and Gamma, which is associated with a higher content of NSC in the stems of these genotypes.

Varietal differences by the amount of the reutilized carbohydrates and by the weight of the transported assimilates of the photosynthesis to the panicle provided the respective differences between the studied genotypes. The sum of these transported substances to the kernels in the intensive varieties was by 5.7 and 6.3% higher than in the extensive varieties. Despite this fact, the TKW in the later was higher than in the former, which was associated with different grain setting on the panicles. The objective evaluation of the provision with plastic material can be based on its transport to the panicle estimated per 100 kernels. These data are presented in the last column of the table. It can be seen that the provision with the initial sources of nutrition for the developing kernels differs depending on the fertilization plan and the variety. In the conditions of optimum fertilization plan ($N_{24}P_{12}K_{12}$), the provision of the kernels with the essential metabolites can worsen in different degree, which is proved by a different rate of their transport to the panicle estimated per 100 kernels. These parameters are lower in the intensive varieties. In the conditions of high availability of minerals, the provision of the kernels with the initial compounds transported from the vegetative organs reduces and the TKW decreases. Varietal differences on the level of the supply to the kernels substrate on the TKW remain established.

DISCUSSION.

The period of formation and filling of grain in crops is one of the most important periods of a plant's ontogenesis when its metabolism switches to the provision of generative organs with the assimilates and mineral elements. The rate of kernels filling and the TKW depend on the intensity of the transportation of these compounds from the vegetative organs to the panicle (ear) [14-17]. The outflow of organic substances is a complicated physiological process that is closely associated with the general metabolism, and primarily, with the photosynthesis and mobilization of the accumulated compounds. The rate of the assimilates synthesis depends on the normal performance of these processes. Their intensive transport to the panicles is determined by its attracting activity that is regulated by the hormones and the grain setting. The initial sources of the compounds synthesis in kernels are the assimilates of the photosynthesis synthesized during the period of ripening, deposits of carbohydrates accumulated in the straw and sheath before the grain filling, the products of destruction of the alive structures of the leaves and other vegetative parts of a plant during their aging and death [18, 19]. However, the quantitative parameters of these sources differ in various varieties of rice, which leads to the variations of TKW and affects the yield [6]. It is important to establish the role of certain initial metabolites during the grain filling for the identification of the causes of the non-uniform decrease in absolute weight of kernels. This issue is well-studied for spring wheat [20-23]. These studies showed that the decrease in TKW was primarily associated with the decrease in photosynthesis productivity caused by the intensive necrosis of leaves during the grain filling that leads to the lack of assimilates. The degree of their influence on the absolute weight of rice kernels is understudied, which determined the authors' interest to this issue.

The lack of assimilates during the grain filling has a different physiological nature. The majority of the upper leaves functions until the end of ripening. Even in the conditions of average mineral availability, the leaves mass during the period of flowering and full ripeness decreased only by 50-55%, in the conditions of optimum and high availability – by 35-45%. The photosynthesis in rice plants continues after the end of the grain filling, which causes the secondary accumulation of carbohydrates in the straw and leads to the appearance of new tillers [6]. At first sight, such leaf apparatus in rice plants should provide the demand of the panicle

in assimilates, but in reality, the deficit of assimilates is observed. Besides, by the beginning of the grain filling, significant reserves of carbohydrates are accumulated. They get nearly completely mobilized for the starch synthesis in kernels, which can also indicate the adequate provision of the kernels with carbohydrate metabolites [18].

It can be suggested that the main physiological reason that causes the deficit of plastic materials for the adequate grain filling is the rate of this process. The period of grain filling in optimal temperature conditions is 12-14 days and it is observed within the second and third week after the flowering [18]. The causes of such intensive accumulation of reserves of nutrients are understudied. Probably, they are associated with the thermophilic nature of this crop and the increased rate of the processes. Another reason for it can be high attracting activity of kernels associated with the increased content of phytohormones. The high rate of filling and a great number of kernels in a panicle leads to the deficit of initial metabolites and the decrease in TKW. There are a number of questions arise: the deficit of what sources of nutrition has the greatest effect on the decrease in the grain absolute weight and what is important in the evaluation of the selection samples for productivity?

Carbohydrates accumulated in the stems before the flowering play an important role for the adequate filling of kernels, which is shown by a high direct correlation ($r = 0.91\pm0.24$-0.64 ± 0.21) between their weigh and TKW. During the period of ripening, these compounds are intensively used for the grain filling and the level of their mobilization is around 80-96%, and the amount of the reutilized substances in the stem has a close direct correlation with TKW ($r = 0.71\pm0.25$) in the conditions of the optimum fertilization. However, in the conditions of high content of nitrogen, this process can slow down, which was observed in Gamma and Atlant varieties that had the share of mobilized carbohydrates in stems decreased because of a negative influence of nitrogen.

However, the main sources of plastic materials used for the grain filling are the products of photosynthesis in leaves during the period of plant developing. The panicle weight gain during the flowering and full ripeness show their contribution in the process of accumulation of nutrients in rice kernels. Part of these assimilates are spent for the maintenance of the gas exchange in the vegetative organs, but primarily, they are transported to the main attracting center (a panicle), where it is used for starch and protein synthesis in kernels [5]. Their mass in the intensive varieties (in the conditions of two fertilization plans) on average was higher than in the extensive ones by 33.6 and 15.2%, respectively, and their share in the total amount of the substances that were transported to the panicles was also higher in the intensive varieties and equal to 87.0-91.1% versus 82.9-84.5% in the extensive genotypes.

Mokronosov A.T. [24] suggested that due to the decrease in the plantstand density during the period of ripening, the assimilating apparatus in crops does not perform in full and its intensity and productivity can significantly increase when the demand in the assimilates in the panicles increases due to a high number of developing kernels. This hypothesis explains a higher weight gain of panicles during the period of ripening in the intensive varieties [25, 26]. The correlation coefficient between the compounds synthesis in a tassel and TKW in the studied varieties has a negative correlation and equals to $r = -0.74\pm0.19$– -0.95 ± 0.14.

The obtained data showed that there was a close correlation between TKW and the amount of the transported substances from the vegetative organs during the period of grain filling (estimated per 100 kernels). Hence, the indicator (metabolites supply to one kernel) indicates the non-uniformity of the donor-receptor relations in the varieties of rice during the period of their ripening. The decreased value of this parameter indicates the insufficiency of the donor capacity and the excessive demands of the acceptor. These drawbacks can be reduced by the selection of plants for rice productivity.

CONCLUSIONS.

Thus, the period of ripening is an important stage in the ontogenesis of rice, when the metabolism in

all the organs is switched to the supply of the kernels with the required plastic material. The rate of kernels filling and TKW depend on the intensity of these compounds transport from the vegetative organs to the panicle. The assimilates of the current photosynthesis remain the main source of materials during the grain filling. Their share in the intensive varieties is 87.0-91.1% and in the extensive varieties - 82.9-84.5%. The study of the production process in differently yielding rice varieties showed that the productivity of the photosynthesis hardly differs in crops with a similar vegetation period in the conditions of optimum fertilization, and their different grain productivity is determined by the character of the distribution of the assimilates in the organs of the tillers. Highly productive rice varieties have a more intensive transport of the plastic materials to the forming panicle of the reproductive tiller, which explains the formation of a great number of ears and kernels that determine the yielding of these genotypes. At the same time, the transport of the assimilates to the side tillers reduces, which increases the share of their reduction and leads to the decrease in the density of a reproductive plantstand. The established character of the distribution of the assimilates in the organs of the rice tillers allows the researchers to identify the morphological and physiological features of plants that determine the yield potential in the intensive and extensive rice varieties. One of the approaches to the issue of the panicle productivity management is the identification of the carbohydrates content in the sheaths and stems that determine the rate of the formation and qualitative parameters of the elements of the productivity.

Adequate filling of the grain depends on the deposits of the carbohydrates in stems accumulated in their tissues before this process and on the weight gain of panicles associated with the increased productivity of photosynthesis during the ripening. Their share in the intensive varieties is 8.9-13.0%, and in the extensive – 15.5-17.1%. It was shown that the deficit of the metabolites for the developing kernels in the intensive varieties affected the TKW. The assimilates transport to the panicles in the extensive varieties was by 13.7-16.8% higher than in the intensive ones, which led to the increase of their absolute weight. The evaluation of the selection samples for the productivity should include both accumulated carbohydrates and the assimilates of the current photosynthesis. These features can be used for the improvement of the physiological model of the intensive genotype of rice.

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