RESEARCH ARTICLE

SABRAO Journal of Breeding and Genetics
54 (4) 700-709, 2022
http://doi.org/10.54910/sabrao2022.54.4.2
http://sabraojournal.org/
pISSN 1029-7073; eISSN 2224-8978

RICE PHENOTYPING THROUGH GRAIN QUALITY TRAITS FOR THE DEVELOPMENT OF NEW GENERATION CULTIVARS

ZH. M. MUKHINA*, N.G. TUMANYAN, E.YU. PAPULOVA, and E.YU. GNENNIY

Federal State Budgetary Scientific Institution, Federal Scientific Rice Centre, Krasnodar, Russia
*Corresponding author's email: agroplazma@gmail.com
Email addresses of co-authors: tngerag@yandex.ru, elya888.85@mail.ru, g.gneka@gmail.com

SUMMARY

The present rice market requires a range of rice products with increased eating and nutritional values. The presented work was carried out within the framework of the breeding program for developing new rice cultivars with desirable grain quality traits based on an integrated approach, using modern methods of trait phenotyping and the genomic approach, post genomic, and cellular technologies. The latest study aimed to phenotype rice cultivars from the Unique Scientific Installation (USI) - Collection of Federal Scientific Rice Centre, Krasnodar, Russia, as sources of valuable grain quality traits. Studied traits included vitreosity, fracturing, and protein and grain amylose content. The coefficient of variation determined the variability of traits and helped identify the best cultivars as sources of valuable traits. The grain quality of harvested sample cultivars showed significant differences. The rice cultivar Thaibonnet gave the best results in terms of grain quality traits and variability. By combining low variability of technologically-tested quality traits and protein content, the rice cultivars Elbrus and Thaibonnet led all the samples. Cultivar Svetlana was characterized by high traits of vitreosity and fracturing and having less variability. The cultivars Leader and Patriot both had high protein content and low trait variability. These cultivars are recommended for use in parental crosses in breeding programs to develop rice genotypes with desirable grain quality traits and nutritional values.

Keywords: Rice breeding, genetic collection, phenotyping, grain quality traits, sources of valuable quality traits

Key findings: Through phenotyping based on rice grain quality traits, the best rice cultivars were identified among the genetic collection with low, moderately high, and high amylose content, and recommended for use in breeding programs for developing rice genotypes with desirable grain quality traits.

Communicating Editor: Prof. Naqib Ullah Khan

Manuscript received: July 12, 2022; Accepted: August 31, 2022.

INTRODUCTION

Rice is one of the top staple food crops for humans. It provides more than 30% of food calories consumed worldwide. Rice yields in 120 countries amount to 650–680 million t from an area of 156–161 million ha. The rice production areas in Russia range from around 140,000–175,000 ha. The modern rice market requires a variety of rice products with increased consumption and nutritional values. Rice products come from grains of different

To cite this manuscript: Mukhina ZHM, Tumanyan NG, Papulova EYU, Gnenniy EYU (2022). Rice phenotyping through grain quality traits for the development of new generation cultivars. *SABRAO J. Breed. Genet.* 54 (4) 700-709. http://doi.org/10.54910/sabrao2022.54.4.2

genotypes, developed from ancient times and through modern breeding technology. Grain quality includes several parameters, comprising grain shape, amylose content, flavor, and other characteristics. The amylose content and gelatinization temperature determine the rice products' culinary and taste qualities (Juliano and Houston, 1972; Perez and Juliano, 1978; Bao *et al*., 2002; Lyman *et al*., 2013; Zhao and Fitzgerald, 2013; Calingacion *et al*., 2014). The contemporary consumption of food products is characterized by the requirements of their high nutritional values.

Rice is an essential source of dietary protein and micronutrients, and most Asian rice-growing countries prefer rice products for their nutritional values (Junfei *et al*., 2015; Duoc *et al*., 2020; Chakrobarty *et al*., 2021). The grain shape and size, the area planted, powdery spots, and grain vitreosity determine the quality appearance of polished rice. The starch granules in the floury areas of the grain are smaller and less densely packed than the larger densely packed granules in the translucent parts of the rice grain (Lisle *et al*., 2000; Nirmaladevi *et al*., 2015; Perdani *et al*., 2018).

The most crucial trait of nutritional value is the amylose content in the reserve starch. Amylose determines the texture of cooked rice however, since cultivars with the same amylose content may differ in the textural properties of the starch dispersion, studying the amylographic characteristics of the starch dispersion is necessary. The culinary properties of rice genotypes are determined by the viscosity of the starch dispersion, evaluated by amylography parameters (Champagne *et al*., 1999; Lisle *et al*., 2000; Zhongquan *et al*., 2016). Therefore, amylography is used as one of the tests, in addition to measuring the amylose content, to improve rice genotype differentiation.

Rice is a rich source of anthocyanins and phenolic compounds that play a key role in human nutrition due to its antioxidant properties of reducing reactive free radicals that damage cells, preventing oxidative damage to lipids and low-density lipoproteins (Vauzour *et al*., 2010; Xiongsiyeeab *et al*., 2018; Ha *et al*., 2020). Breeding cereals for high antioxidant content as nutritional factors are recognized as relevant and accomplished worldwide (Polonsky *et al*., 2018). In rice, substances with antioxidant activity include phenolic compounds, tocopherols, tocotrienols, and γ-oryzanol (Walter and Marchesan, 2011). In Russia, studies began breeding and grading rice cultivars with a colored grain pericarp and the highest content of antioxidants (Tumanyan *et al*., 2016).

The climatic and agrotechnical conditions of rice cultivation have a great influence on the grain yield and quality. For example, high temperatures and low solar radiation during ripening in Japan increased the frequency of chalky grains in rice (Morita *et al*., 2004, 2016; Ishimaru *et al*., 2018). High air temperatures during rice ripening also effect and reduce the amylose and protein content (Cooper *et al*., 2008; Lin *et al*., 2010). The breeding process establishes a high nutritional value based on the use of a wide range of rice genotypes and the latest breeding methods. The relevance of breeding in rice cultivars influences s the taste of the consumer and the producer to cultivate grains with high-yielding characteristics of head rice and the parameters of a healthy diet (Han *et al*., 2004; Koutroubas *et al*., 2004; Addison *et al*., 2015; Odoom *et al*., 2021).

The eating and cooking quality (ECQ) of rice is critical to its economic value in the market, which is of paramount importance in rice breeding programs. Worldwide advances in genetic research on ECQ and the prospects of further improving ECQ in rice depend on innovations in gene and genome editing that can excel the ECQ of rice. Significant genes and quantitative trait loci (QTLs) regulate starch composition by influencing amylose content and thermal and adhesive properties. Several genes have been identified for ECQ properties, such as, protein content and aroma properties. Marker-assisted breeding has identified rare alleles that determined superior ECQ traits in different rice genotypes (Sreenivasulu *et al*., 2022). It is known that most cultivated rice with important aroma traits belongs to allelic variations of badh2-E2 and badh2-E7, and functional molecular markers SNP, SNP_badh2-E2, and SNP_badh2-E7 can also be used to improve the genetics of aromatic rice with the help of biotechnological techniques in rice breeding (Li *et al*., 2020).

In breeding programs, crossing parental genotypes to obtain cultivars with high grain quality traits and nutritional values starts with donor selection of valuable quality traits and the selection of the best lines per plant biometric, agrobiological, and grain quality traits at all the stages. The latest study aimed to phenotype genetic collection of the Unique Scientific Installation (USI) - 'Collection of Federal Scientific Rice Centre' as a source of valuable grain quality traits.

MATERIALS AND METHODS

Meteorological conditions

The weather conditions for growing rice hinged on the values of the sum of effective temperatures and average daily air temperatures in April-September of 2019–2021. The total sum of effective temperatures was higher in June 2020 than in 2021 (Figures 1 and 2). During the rice tillering phase, the average daily temperature on the second day of June, was 1.8°C higher in 2020 than in 2021. In August 2021, the sum of effective temperatures during initiation and panicle formation was also lower than in 2020. The 10-day average temperatures in August and September, when the grain reaches technical and full ripeness, were 0.3°C lower on the first day of August and 6.7°C lower on the first day of September. In 2019, both the indicators remained higher compared to 2021.

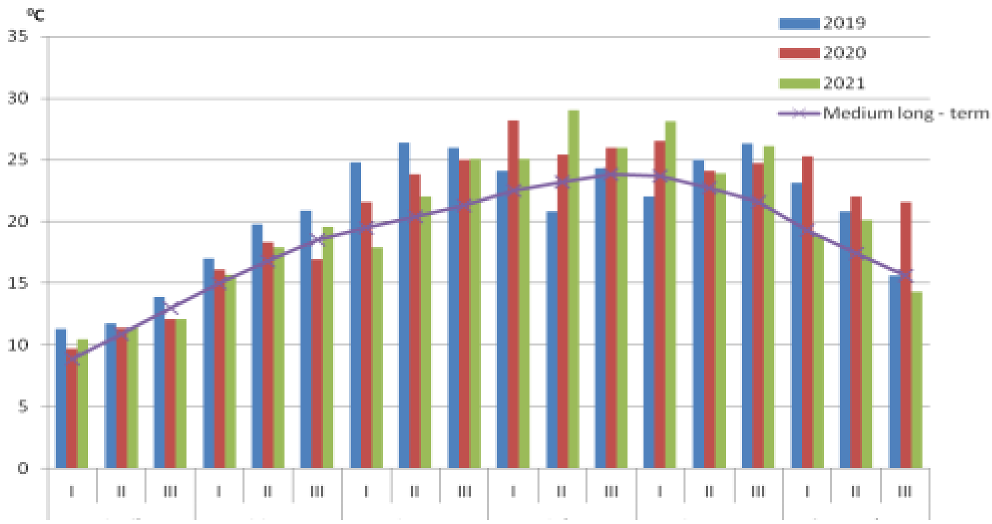

Figure 1. Average daily air temperatures in April-September 2019–2021.

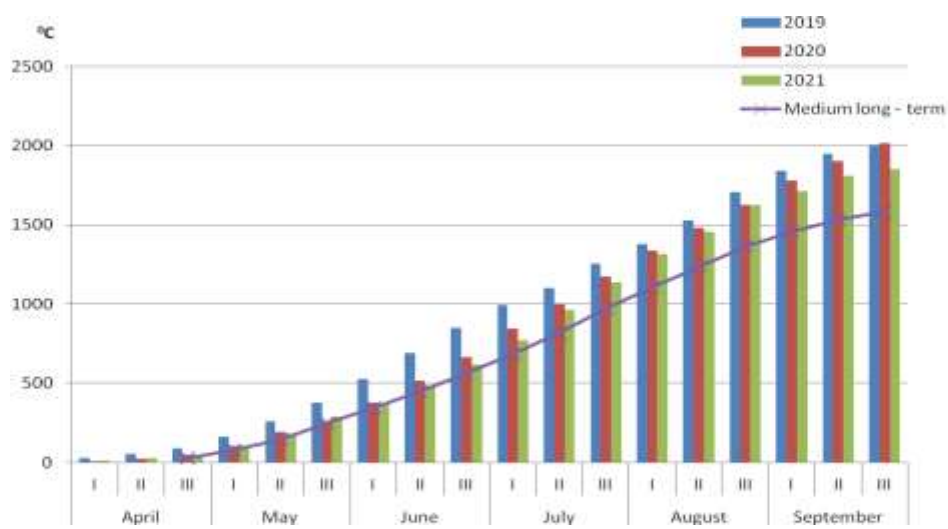

Figure 2. The sum of perennial air temperatures in April-September 2019–2021.

Place of study

In the experimental plot at the Federal Scientific Rice Centre, Krasnodar, Russia (N 45°03′51″ E 38°40′44″), the soils consisted of degraded forest-like and alluvial rocks, predominantly of heavy granulometric composition, rice, meadow-chernozem, with the most fertile and fairly thick humus horizon, almost-chernozem like in terms of nutrient content. The thickness of the humus horizon was from 100 to 130 cm however, it can reach up to 80 cm with a humus content in the upper horizon within 3%–4% and gross humus reserves in the A+B horizon from 300 to 450–600 t ha^{-1}. In horizon A, the content of physical clay was 63%–73%, silt (35%–44%), and dust (45%–58%). The content of gross nitrogen and phosphorus in the upper horizon was 0.14%–0.26% and 0.13%–0.20%, respectively. The capacity of the soil absorbing complex ranges from 25–30 to 35–45 mg-eq. 100 g^{-1}, 70%–80% saturated with calcium, less magnesium, and 0.4%–3.0% sodium. The available mobile elements of mineral nutrition were quite high; in horizon A the pH was 6.6–7.9. The arable horizon of the experimental plot at the Federal Scientific Rice Centre, Krasnodar, Russia, was characterized by the pH of 7.5, the total humus content (4.2), easily hydrolyzable nitrogen (7.3 mg 100 g^{-1}), total nitrogen (0.22%), mobile phosphorus (2.9 mg 100 g^{-1}), total phosphorous (0.25%), exchange potassium (37.4 mg 100 g^{-1}), and total potassium (1.2%) (Kumeiko and Tumanyan, 2019).

Plant material

The plant material for the study comprises 14 rice cultivars *Oryza sativa* L., i.e., Violeta, Yakhont, Rubin, Kurazh, Veles, Flagman, Leader, Patriot, Elbrus, Mavr, Svetlana, Gagat, Zlata, and Thaibonnet. The yield of cultivars was obtained from the Experimental Production Plot at the Federal Scientific Rice Centre in 2019–2021. Thirteen cultivars bred by FSBSI-Federal Scientific Rice Centre and one cultivar of foreign breeding, Thaibonnet, served as the research material. The rice cultivars showed a vegetation period of 108 to 125 days, a plant height of 75 to 110 cm, a panicle length of 13 to 22 cm, and three cultivars with a colored pericarp (Table 1).

Table 1. Rice cultivar with various agronomic traits, 2019–2021.

Cultivars	Growing season (days)	Yield (t/ha)	Plant height (cm)	Panicle long (cm)	Grain color	Cultivars approved for use
Violetta	120-122	5.5-6.2	80-85	14-16	white-grain	2007
Yakhont	117-122	8.8-9.2	100-110	17-18	white-grain	2019
Kurazh	118-123	7.6-8.2	90-100	15-17	white-grain	2013
Veles	120-125	8.2-8.8	85-90	17-18	white-grain	2020
Flagman	115-120	8.7-8.9	85-90	16-18	white-grain	2007
Leader	120-125	7.8-8.1	90-95	13-15	white-grain	2000
Patriot	108-116	8.3-9.1	85-100	16-17	white-grain	2017
Elbrus	116-118	8.7-9.2	85-87	15-16	white-grain	-
Rubin	115-118	7.0-7.8	80-90	14-16	red-grain	2012
Mavr	118-120	6.5-6.8	70-80	20-22	black-grain	2011
Svetlana	115-117	6.9-7.2	98-93	20-22	white-grain	-
Gagat	120-121	6.5-7.0	80-90	18-22	black-grain	2014
Zlata	116-119	7.0-7.9	96-101	19-21	white-grain	2019
Thaibonnet	123-126	6.8-7.2	75-80	16-17	white-grain	-

Research methodology

The study performed experiments at the rice quality laboratory using the following methods/equipment: GOST 10843-73 for the mass of 1000 absolutely dry grains (a.d.g.) and filminess; GOST 10986-76 for vitreosity, and GOST ISO 6647-2-2015 for rice determination of amylose content. The use of an Infralum FT-10 device measured protein content.

Statistical analysis

The mathematical data processing was carried out using Microsoft Excel.

RESULTS AND DISCUSSION

The development of modern technologies for the rice breeding process requires the study and analysis of experimental data obtained at different stages, including grain quality and selection of valuable breeding materials based on their performance, maintaining such studies until stable genotypes are attained. Experimental data on grain quality result from phenotyping methods and genome analysis by high-throughput sequencing. It gives a detailed characterization of the phenotypes and genotypes in the studied rice breeding samples. In the latest study, the use of high-tech methods for phenotyping breeding materials obtained from the Unique Scientific Installation (USI) 'Collection of genetic resources of rice, vegetables, and melons' displayed the studied technological and nutritional characteristics of rice grains (protein and amylose content, vitreosity, and fracturing).

By the trait 'amylose content', rice cultivars got classified into glutinous (0%–2% amylose), very low amylose (from 2% to 9%), low amylose (from 10% to 20%), medium amylose (21%–25%), moderately high amylose (26%–27%), and high amylose (above 27%). In rice grain starch, the amylose content fortifies the nutritional values and culinary qualities of the end products of rice. During their amylose content evaluation, four groups resulted in classifying the rice cultivars, i.e., glutinous, low amylose, moderately high amylose, and high amylose rice cultivars.

Rice cultivar Violetta was glutinous, and its amylose content did not change over the years. Six cultivars got classified with low amylose content, i.e., Yakhont, Kurazh, Veles, Flagman, Leader, and Patriot. The amylose content in rice cultivar Yakhont increased by 0.7% in 2020 compared with 2019 and 2021. The amylose content of cultivar Kurazh was lower in 2019 (by 1.7%) and 2021 (by 1.4%) compared with 2020. The same parameter for rice cultivar Veles increased in 2020 compared with 2019 (0.3%) and 2021 (0.8%). In cultivar Flagman, the amylose content was lower in 2019 by 0.3% and in 2021 by 0.8%. The said trait slightly increased in cultivar Leader in 2020, compared with 2019 (0.1%) and 2021 (0.9%). In cultivar Patriot compared with 2020, the amylose content was significantly lower in 2019 and 2021 by 1.2% and 1.7%, respectively (Table 2). Six rice cultivars received a moderately-high amylose content classification, i.e., Elbrus, Rubin, Mavr, Svetlana, Gagat, and Zlata. The cultivars Elbrus and Mavr gave no group with low- and moderately-high amylose content, however, their amylose values for at least one year of the study at above 20.0% allowed them under the moderately-high amylose group.

For cultivar Elbrus in 2020, the amylose content was higher by 0.2% (2019) and 1.3% (2021). This trait indicator in Rubin increased by 1.3% in 2020 and 0.8% in 2021 compared with 2019. The amylose content in cultivar Mavr in 2019 and 2021 was the same, and in 2020 by 4.8%. In cultivar Svetlana, the said trait slightly changed over the years, and compared with 2019, it increased by 0.3% in 2020, while in 2021, it decreased by 0.3%. In moderately high-amylose rice cultivars Gagat and Zlata, slight changes were noted for amylose content. In the black grain cultivar Gagat, this parameter did not differ in 2019 and 2020, however, in 2021, it increased by 0.5%. In cultivar Zlata, the amylose content was higher in 2020 by 0.4% (2019) and 0.5% (2021). The only cultivar Thaibonnet was recorded with a high amylose content (27.1%–28.3%), and had an increase in 2020 compared with 2019 (0.7%) and 2021 (1.2%). The amylose content in all groups of cultivars varied during 2019, 2020, and 2021, which confirms the past findings of Zhongquan *et al.* (2016).

The protein content in rice grain defines its eating and nutritional values. Differences in protein content in yields of 2019–2021 were confirmed, which resembled the past findings (Lin *et al.,* 2010). The protein content of the glutinous cultivar Violetta was the highest in 2021 and higher by 0.4% (2019) and 1.0% (2020). A group of low amylose rice cultivars showed an increase in protein content in 2020 (Table 3). The protein content was higher in cultivar Leader during 2020 than in 2019 and 2021 by 0.2% and 0.4%, respectively. In cultivar Patriot, the protein content changed slightly over the years and was lower in 2019 as compared with 2020 and 2021 by 0.4% and 0.2%, respectively.

The group of rice cultivars with moderately-high amylose content exhibited a similar tendency of protein content in the grain. The Elbrus in 2020 exhibited the highest protein content noted for a cultivar, which was higher than in 2019 and 2021 by 0.4% and 0.5%, respectively. The protein content of the black-grain cultivar Mavr and Svetlana gave similar values in 2019 and 2021 and was lower by 1.0% and 0.3%, respectively, than in 2020. The high-amylose cultivar Thaibonnet exhibited

Table 2. Amylose content in grain starch of rice cultivars in 2019–2021.

Cultivars	Amylose content (%)		
	2019	2020	2021
Glutinous cultivars			
Violetta	2.0	2.0	2.0
Low-amylose cultivars			
Yakhont	17.1	17.8	17.1
Kurazh	17.5	19.2	17.8
Veles	18.0	18.3	17.5
Flagman	17.5	18.3	17.0
Leader	18.8	18.9	18.0
Patriot	16.7	17.9	16.2
Moderately high-amylose cultivars			
Elbrus	19.6	19.8	18.5
Rubin	20.2	21.5	21.0
Mavr	17.2	22.0	17.2
Svetlana	20.3	20.6	20.0
Gagat	22.0	22.0	22.5
Zlata	21.9	22.3	21.8
High-amylose cultivars			
Thaibonnet	27.6	28.3	27.1

Table 3. Protein content in grain of rice cultivars in 2019–2021.

Cultivars	Protein content (%)		
	2019	2020	2021
Glutinous cultivars			
Violetta	8.9	8.3	9.3
Low-amylose cultivars			
Yakhont	7.3	7.8	7.3
Kurazh	8.3	8.8	8.1
Veles	8.2	8.8	8.1
Flagman	7.7	8.5	8.0
Leader	8.9	9.1	8.7
Patriot	8.4	8.8	8.2
Moderately high-amylose cultivars			
Elbrus	8.1	8.5	8.0
Rubin	8.5	8.9	8.2
Mavr	7.8	8.8	7.8
Svetlana	7.8	8.1	7.8
Gagat	8.8	9.1	8.3
Zlata	8.9	8.2	8.7
High-amylose cultivars			
Thaibonnet	8.2	8.8	8.4

an increase in protein content in 2020 compared with 2019 and 2021 by 0.6% and 0.4%, respectively.

The grain vitreosity parameter characterizes the consumer requirements of the rice end products and depends on the agro-climatic conditions of the rice crop. Rice grain with chalky spots is rationed in commodity lots. Cultivars with chalky spots were used for cooking certain dishes, such as risotto and paella. The glutinous rice cultivar Violetta had a vitreosity of 0% over all the years of research. In low-amylose cultivars, vitreosity decreased over the years compared with 2019, for cultivar Leader by 2% and 19%, Patriot by 15%, and Svetlana by 3% and 11%, respectively. The vitreosity of cultivar Veles was the same in 2019 and 2020, however, in 2021, it decreased by 6%. For cultivar Flagman, the vitreosity was lower in 2019 than in 2020 by 7% and higher than in 2021 by 12% (Table 4).

The highest vitreosity in cultivar Elbrus was noted in 2020, while in 2019 and 2021, it was lower by 1% and 5%, respectively. In Rubin, compared with 2019, the indicator decreased in 2020 and 2021 by 4% and 14%, respectively. The moderately-high amylose

Table 4. Grain vitreosity of rice cultivars in 2019–2021.

Cultivars	Vitreosity (%)		
	2019	2020	2021
Glutinous cultivars			
Violetta	0	0	0
Low-amylose cultivars			
Yakhont	91	89	85
Kurazh	93	88	77
Veles	91	91	85
Flagman	87	94	75
Leader	92	90	73
Patriot	87	72	72
Moderately high-amylose cultivars			
Elbrus	72	73	68
Rubin	72	68	58
Mavr	76	77	72
Svetlana	93	90	82
Gagat	89	85	70
Zlata	76	75	81
High-amylose cultivars			
Thaibonnet	98	98	86

Table 5. Grain fracturing of rice cultivars in 2019–2021.

Cultivars	Fracturing (%)		
	2019	2020	2021
Glutinous cultivars			
Violetta	-	-	-
Low-amylose cultivars			
Yakhont	10	11	10
Kurazh	16	18	4
Veles	3	10	2
Flagman	37	25	21
Leader	30	36	22
Patriot	18	25	16
Moderately high-amylose cultivars			
Elbrus	24	36	26
Rubin	14	20	16
Mavr	21	18	22
Svetlana	3	12	2
Gagat	12	17	15
Zlata	39	39	4
High-amylose cultivars			
Thaibonnet	2	3	3

cultivar Zlata had the lowest percentage of this trait in 2020, while in 2019 and 2021 its vitreosity was 1% and 6% higher, respectively. In the cultivar Gagat, the percentage vitreosity decreased over the years and was less in 2020 by 4% and in 2021 by 19%. The high amylose cultivar Thaibonnet had the same vitreosity in 2019 and 2020, while in 2021, it decreased by 12%.

Fracturing is the most critical indicator of rice grain quality, which determines the milling yield and milled rice quality. Highly cracked grain during peeling and grinding is characterized by a low head rice content and a high content of broken rice. According to the percentage fracturing, the classification of rice cultivars comprised cultivars with low (below 10%), medium (10%–30%), and high fracturing (above 30%). Notably, the glutinous cultivar Violetta showed no cracked grains(Table 5). The low-amylose rice cultivars Yakhont and Rubin showed medium fracturing, which was maximum in 2020 and was lower in 2019 by 1% and 6%, and in 2021 by 1% and 4%, respectively. In cultivar Veles, this trait indicator was low in 2019 and 2021, while in 2020, the fracturing of this cultivar was higher.

Cultivar Elbrus in 2020 showed high fracturing , while in 2019 and 2021, it was lower by 12% and 10%, respectively.

Insignificant differences were recorded for the said trait in cultivar Mavr, and compared with 2020, the fracturing was 3% and 4% higher in 2019 and 2021, respectively. Cultivar Svetlana showed a low fracturing in 2019 and 2021, while in 2020, it was higher by 9% and 10% than in 2019 and 2021, respectively. The high amylose cultivar Thaibonnet showed low rates of this trait, which did not have significant differences over the years. The parameters of vitreosity and grain fracturing exhibited variability over the study years, consistent with the past findings (Lisle *et al.,* 2000, Lyman *et al*., 2013).

Furthermore, trait variation was studied, which characterizes cultivar variability by the trait, and as a rule, it is determined by the coefficient of variation. It is considered weak when the coefficient of variation is less or equal to 10%, medium - when the coefficient of variation is 10%–33.3%, and strong when more than 33.3%. The coefficient of variation makes it possible to compare with the average trait level in relative terms and thereby assess the stability of the rice cultivars by traits. Table 6 presents the average values and variability of quality traits of rice cultivars, showing 2.2%–7.1% demonstrated a low variation of the trait's protein content in the grain. The coefficient of variation was more than 5% in rice cultivars Violetta and Mavr (Table 6). For 'amylose content,' a low variation of the trait (1.2%–5.2%) was also noted in all the rice cultivars except Mavr (14.7%). The variability of grain vitreosity in cultivars was higher probably determined by the strong influence of weather conditions. Comparable with other cultivars, Violetta, Yakhont, Veles, Elbrus, and Mavr were characterized by low trait variability (up to 4%). The fracturing confirmed its characteristic as the most variable, and the high variability displayed in rice cultivars Kurazh, Veles, Svetlana, and Zlata.

The grain quality of all the rice cultivars harvested in 2019–2021 revealed differences. According to the traits of vitreosity and fracturing in cultivars a decrease in grain quality was noted in 2020, i.e., exposing a higher fracturing for each cultivar, while lower for vitreosity. The features characterizing the nutritional value and culinary qualities, protein and amylose content also differed in terms of indicators. In 2020, the protein nutritional value was higher and the amylose content also increased. The average 10-day temperature in the second day of June, during the rice tillering phase, was higher in 2020 than in 2021. In 2021, the sum of effective temperatures during the initiation and panicle formation in August was also lower than in 2020. Average 10-day temperatures in August and September, when the grain reaches technical and full ripeness, were 0.3°C lower on the first day of August and 6.7°C lower on the first day of September. In 2019, both indicators remained higher compared with 2021. Thus, higher average 10-day temperatures and the sum of effective temperatures probably lead to increase fracturing, amylose, and protein content, and a decrease in vitreosity index.

The question of the best genotypes in the study of phenotyping concerning quality traits and their variability was answered by the optimal combination of high values of quality traits and low trait variability. Cultivars with high quality traits included Yakhont (vitreosity 88%, fracture 10%), Veles (89% and 5%, respectively), Svetlana (88% and 6%), and Thaibonnet (97% and 3%). Cultivars with low variability of quality traits included Yakhont,

Table 6. Mean values and variability of grain quality traits of rice cultivars.

Cultivars	Variability of technological quality traits							
	Vitreosity		Fracturing		Amylose content		Protein content	
	Mean (%)	CV (%)	Mean (%)	CV (%)	Mean (%)	CV (%)	Mean (%)	CV (%)
Violetta	0	0	-	-	2.0	0.0	8.8	5.7
Yakhont	88	3.5	10	5.6	17.3	2.3	7.5	3.9
Kurazh	86	9.5	12	59.8	18.2	5.0	8.4	4.3
Veles	89	3.9	5	87.2	18.0	2.3	8.4	4.5
Flagman	85	11.3	28	30.1	17.6	3.7	8.1	5.0
Leader	85	12.3	29	23.9	18.6	2.7	8.9	2.3
Patriot	77	11.3	20	24.0	16.9	5.2	8.5	3.6
Elbrus	71	3.7	29	22.4	19.3	3.6	8.2	3.2
Rubin	66	10.9	17	18.3	20.9	3.1	8.5	4.1
Mavr	75	3.5	20	10.2	18.0	14.7	8.1	7.1
Svetlana	88	6.4	6	97.2	20.3	1.5	7.9	2.2
Gagat	81	12.3	15	17.2	22.0	1.2	8.6	4.2
Zlata	77	4.1	27	73.9	22.2	1.3	8.7	4.6
Thaibonnet	97	1.2	3	21.6	27.7	2.2	8.5	3.6

Elbrus, Mavr, and Thaibonnet. For amylose content, the selection of the best cultivars was not carried out, since the criterion indicators did not show the best or worst. Rice protein does not contain gluten, so it is not an allergen. Differences in protein content in rice grain can be small ranging from 7.5% to 8.9%. The cultivars Svetlana, Leader, Patriot, Elbrus, and Thaibonnet were identified as the best in terms of trait variability. Cultivars Leader and Flagman (21%–37%) were classified as the worst cultivars by the trait of fracturing, while Rubin for the trait vitreosity (58%–72%).

CONCLUSIONS

Rice cultivar Thaibonnet came up as the best cultivar in terms of grain quality traits and variability. Cultivars Elbrus and Thaibonnet gave better results with the combination of low variability of technologically-tested quality traits and protein content. Cultivars Svetlana and Veles revealed high values of vitreosity and fracturing. Cultivars Leader and Patriot had high protein content and low trait variability. The study recommends these cultivars be used as parental crosses in breeding programs to develop rice genotypes with high grain quality traits and nutritional values.

ACKNOWLEDGMENTS

The latest research was carried out with the support of the Russian Scientific Foundation and Kuban Scientific Foundation Project "Innovation Breeding Technology for Developing Rice Cultivars with High Grain Quality. № 22-16-20015, https://rscf.ru/project No. 22-16-20015

REFERENCES

Addison M, Sarfo-Mensah P, Edusah SE (2015). Assessing Ghana's initiative of increasing domestic rice production through the development of rice value chain. *Glob. J. Agric. Econ. Ext. Rural Dev.* 3(4): 230-237.

Bao JS, Sun M, Corke H (2002). Analysis of the genetic behavior of some starch properties in *indica* rice (*Oryza sativa* L.): Thermal properties, gel texture, swelling volume. *Theor. Appl. Genet.* 104: 408-413.

Calingacion M, Laborte A, Nelson A, Resurreccion A, Concepcion JC, Daygon VD, Manful J (2014). Diversity of global rice markets and the science required for consumer-targeted rice breeding. *PLoS One*. 9: e85106.

Chakrobarty T, Al-Galib MA, Islam MZ, Rahman MA (2021). Adoption and adaptability of modern Aman rice cultivars in Faridpur Region – Bangladesh. *SABRAO J. Breed. Genet.* 53(4): 659-672. https://doi.org/10.54910/sabrao2021.53.4.9.

Champagne ET, Bett KL, Vinyard BT, McClung AM, Barton II FrE, Moldenhauer K, Linscombe S, McKenzie K (1999). Correlation between cooked rice texture and rapid visco analyser measurements. *Cereal Chem*. 76(5): 764-771.

Cooper NTW, Siebenmorgen TJ, Counce PA (2008). Effects of nighttime temperature during kernel development on rice physicochemical properties. *Cereal Chem.* 85: 276-282.

Duoc HV, Tam VT, Tuan TM, Tram NTN, Uyen NTP, Ha PTT (2020). Screening of rice (*Oryza sativa* L.) genotypes with low amylose content by using molecular markers. *SABRAO J. Breed. Genet*. 52(3): 341-354.

Ha PTT, Nguyen NTT, Linh DTN, Lang NT, Buu BC (2020). Evaluation of rice germplasm for yield traits and amylose content under drought stress. *SABRAO J. Breed. Genet.* 52(1): 64-74.

Han Y, Xu M, Liu X, Yan C, Korban SS, Chen X, Gu M (2004). Genes coding for starch branching enzymes are major contributors to starch viscosity characteristics in waxy rice (*Oryza sativa* L.). *Plant Sci*. 166: 357-364.

Ishimaru T, Nakayama Y, Aoki N, Ohsumi A, Suzuki K, Umemoto T, Yoshinaga S, Kondo M (2018). High temperature and low solar radiation during ripening differentially affect the composition of milky-white grains in rice (*Oryza sativa* L.). *Plant Prod. Sci.* 21(4): 370-379.

Juliano BO, Houston DF (1972). The rice caryopsis and its composition. *Ric.: Chem. and Tech.*, *Am. As. Cer. Chem., St. Paul, MN.* 16-74.

Junfei G, Jing Ch, Lu Ch, Zhiqin W, Hao Zh, Jianchang Y (2015). Grain quality changes and responses to nitrogen fertilizer of *japonica* rice cultivars released in the Yangtze River Basin from the 1950s to 2000s. *The Crop J.* 3(4): 285-297.

Koutroubas SD, Mazzini F, Pons B, Ntanos DA (2004). Grain quality variation and relationships with morphophysiological traits in rice (*Oryza sativa* L.) genetic resources in Europe. *Field Crop Res.* 86: 115-130.

Kumeiko TB, Tumanyan NG (2019). Grain damage of rice varieties in the form of dark spots in the field conditions. Collection of the Materials of V International Scientific and Practical Conference. The Role of Physiology in Biochemistry in the Introduction of Agricultural Plant Breeding. Vol. 1: pp. 225-229.

Li W, Zeng X, Li S, Chen F, Gao J (2020). Development and application of two novel functional molecular markers of BADH2 in rice. *Electr J. Biotechnol*. 46: 1-7.

Lin CJ, Li CY, Lin SK, Yang FH, Huang JJ, Liu YH, Lur HS (2010). Influence of high temperature during grain filling on the accumulation of storage proteins and grain quality in rice (*Oryza sativa* L.). *J. Agric. Food Chem.* 58(19): 10545-10552.

Lisle AJ, Martin M, Fitzgerald MA (2000). Chalky and translucent rice grains differ in starch composition and structure and cooking properties. *Cereal Chem.* 77: 627-632.

Lyman NB, Jagadish KSV, Nalley LL, Dixon BL, Siebenmorgen T (2013). Neglecting rice milling yield and quality underestimates economic losses from high-temperature stress. *PLoS One*. 8: e72157.

Morita S, Shiratsuchi H, Takahashi J, Fujita K (2004). Effect of high temperature on grain ripening in rice plants. -Analysis of the effects of high night and high day temperatures applied to the panicle and other parts of the plant. *Jpn. J. Crop Sci.* 73: 77-83.

Morita S, Wada H, Matsue Y (2016). Countermeasures for heat damage in rice grain quality under climate change. *Plant Prod. Sci.* 19: 1-11.

Nirmaladevi G, Padmavathi G, Kota S, Babu VR (2015). Genetic variability, heritability and correlation coefficients of grain quality characters in rice (*Oryza sativa* L.). *SABRAO J. Breed. Genet*. 47(4): 424-433.

Odoom DA, Kugbe JX, Dzomeku IK, Berdjour A, Boateng DO, Yaro RN, Wireko P, Sam EK, Ghanney P (2021). Impact of production inputs and timing on crackness of rice in Northern Ghana. *Int. J. Agric*. 9982911

Perdani AY, Mulyaningsih ES, Paradisa YB (2018). Diversity of some Indonesia local glutinous rice (*Oryza sativa* L. Var. Glutinous) based on agromorphological and RAPD markers. *SABRAO J. Breed. Genet*. 50(2): 85-100.

Perez CM, Juliano BO (1978). Modification of the simplified amylose test for milled rice. *Starch* 30: 424-426.

Polonsky VI, Loskutov IG, Sumina AV (2018). Breeding for the content of antioxidants in grain as a promising direction for obtaining healthy foods. *Vavilov's J. Genet. Breed*. 22(3): 343-352.

Sreenivasulu N, Zhang C, Tiozon RNJr, Liu Q (2022). Post-genomics revolution in the design of premium quality rice in a high-yielding background to meet consumer demands in the 21st century. *Plant commun.* 3(3): 100271.

Tumanyan NG, Papulova EYu, Kumeiko TB, Esaulova LV, Zelensky GL, Ostapenko NV (2016). Classification of colored rice varieties (with red and black grain pericarp) as objects of the genetic collection based on the analysis of quantitative quality traits. *Achiev. Sci. Technol. Agro-Ind. Complex* 30(3): 57-61.

Vauzour D, Rodriguez-Mateos A, Corona G, Oruna-Concha MJ, Spencer JPE (2010). Polyphenols and human health: Prevention of disease and mechanisms of action. *Nutrients* 2(11): 1106-1131.

Walter M, Marchesan E (2011). Phenolic compounds and antioxidant activity of rice. *Braz. Arch. Biol. Tech.* 54(2): 371-377.

Xiongsiyeeab V, Rerkasemc B, Veeradittakitb J, Sittichai CHS, Chanakan L, Thebault P (2018). Variation in grain quality of upland rice from Luang Prabang Province, Lao PDR. *Rice Sci.* 25(2): 94-102.

Zhao X, Fitzgerald M (2013). Climate change: Implications for the yield of edible rice. *PLoS One* 8: e66218.

Zhongquan S, Shanghai JT, Tianming Y, Xiaoting Y, Shanghai J, Jinsong B (2016). Physicochemical properties and starch digestibility of in-kernel heat-moisture treated waxy, low, and high-amylose rice starch. *Starch* 69(7-8): 1600164.