New genetic resources and technologies in development of blast resistant rice forms for greening the rice growing industry

T L Korotenko, E G Savenko, Zh M Mukhina and V A Glazyrina

All-Russian Rice Research Institute, 3 Belozerny, 350921 Krasnodar, Krasnodar region, Russia

E-mail: korotenko.tatyan@mail.ru

Abstract. To accelerate development of competitive new-generation rice varieties adapted for environmentally friendly non-pesticide farming, we used the achievements of modern Russian and Chinese national rice breeding. The article observes the technologies of developing rice initial forms combining economically valuable traits with long-term resistance to biotic stressors (blast) using modern methods of phenotyping and genotyping as well as experimental haploidy with subsequent experimental development of breeding resources.

1. Introduction

Currently, rice crops are located in 115 countries on an area of 156-161 million ha, the annual grain production in the world is about 650-680 million tons. Rice farming employs more than 50% of the labor force of the agricultural sector of the planet. Demand for rice is increasing annually and according to the FAO forecast by 2020 it will amount to 781 million tons. The largest rice producers in the world are China and India — about 29% and 21% of the global volume, respectively. Indonesia, Bangladesh, Vietnam, Thailand, the Philippines, Brazil, the USA and other countries produce slightly less. At the same time, Russia is one of the twenty countries exporting rice. About 80% of all rice produced in Russia falls on Krasnodar region, and therefore this crop is strategic for the southern region. In the volume of cereals consumed by the population of our country, rice is more than 30%, since it has dietary, preventive and therapeutic properties. Rice growing in Russia is fully provided with seeds of domestic origin.

About 30% of rice systems in Krasnodar region are located in the sanitary zone, where the range of chemical protective equipment used is sharply limited and the use of aviation is prohibited. Permitted pesticides are prescribed to be applied by ground and only if absolutely necessary. As practice shows, chemical protection of plants in some cases is either ineffective (due to the untimely use of preparations), or unprofitable (due to sharply increased prices for chemical preparations and aviation services), or is environmentally contraindicated. In addition, in rice crops, where chemical means of protection are systematically used, there is a real danger of the appearance of mutant forms of blast fungus resistant to fungicides. In this regard, the main method of protecting rice from blast should be the introduction of high-yielding and pathogen-immune varieties into production [1].

Grain crop rice of tropical origin belongs to the hygrophytic type of plants, grows and yields on soils completely saturated with moisture and flooded with a layer of water. The presence of a layer of water from seedling to grain ripening is a biologically, physiologically and environmentally necessary
condition. At the same time, rice is very sensitive to soil fertility. Moreover, in the Kuban, land masses are being developed for this crop, on which meadow-bog and saline soils with close occurrence of highly mineralized groundwater were widespread. For the successful use of such lands for rice, agrochemical and land reclamation measures are necessary, the washing water regime and balanced mineral nutrition N: P: K must be maintained. A number of toxic substances are used to control weeds and diseases in rice growing: anti-cereal herbicides, herbicides against marsh weeds, and also fungicides against fungal diseases.

The most common fungal diseases in rice crops in Russia: alternariosis (pathogen — Alternaria oryzae Har. Ital); helminthosporiosis (pathogen — Helmintosporium oryzae Br. de Haan); blast (pathogen — Pyricularia oryzae Cav.); Fusarium causing root rot (pathogen — Fusarium oxysporum) and so-called drunk rice (pathogen — Fusarium graminearum Seh.) which are used to control the chemical treatment of seeds and plants during flowering. Blast (pathogen — fungus Magnaporthe grisea (Herbert) Barr Yaegashi & Udagawa (anamorph Pyricularia grisea) is the most dangerous and harmful rice disease, widespread in most rice-growing regions of the world, including Russia and China. The World Institute of Mycology has registered this disease in more than 80 countries in recent years, the disease has been highly harmful in all areas of rice cultivation in the world. [2].

Blast epiphytoty in 2013 showed that most rice varieties cultivated in Kuban are susceptible to the pathogen Pyricularia oryzae Cav. This year, farms were forced to process rice with fungicides on 192.3 thousand ha, which amounted to 152.3% of the total crop area. The processing costs exceeded 288 million rubles (with the processing cost of 1,500 rubles per ha). In addition, the cost of losses from blast should be added with the lost yield and a decrease in grain quality. However, under the conditions of this year’s epiphytoty, several Kuban rice varieties were not affected by blast and did not require treatment with fungicides. Among them were short-stemmed varieties of intensive type Kumir and Sonnet, universal ones — Gamma, Sonata, Olymp and unpretentious ones — Leader, Atlant, Yuzhny [3].

High farming standatrd in rice cultivation dictate an urgent need to reorient national breeding strategies towards an adaptive course and greening the industry, which involves a combination of effective agricultural techniques, chemicalization, optimal irrigation, increasing soil fertility by alternating crops in crop rotation and increasing grain yield using new varieties resistant to external stressors. A number of foreign authors note that it has been possible to increase rice production over the past three-four decades in rice-growing countries of the world by developing new resistant varieties that are responsive to fertilizer doses and with sufficient amount of irrigation water. However, these conditions have exhausted themselves and the efficiency of the use of applied resources has led to the fact that productivity has approached the theoretical limit [4]. Arid irrigated rice growing areas are mainly concentrated in South and Central China, South and East India and all of Southeast Asia, where there has recently been a shortage of irrigation water at critical stages of plant vegetation and crop growth. Scientists are observing climate change, which often leads to a sharp increase in day and night temperatures, creating more frequent floods in coastal zones and river plains, severe droughts in favorable rainfalls and lack of water in irrigated fields. Rice production under these conditions is becoming increasingly vulnerable and unsustainable [5].

Taking this into account, it is advisable to revise varietal policies, preferring the development and introduction of rice varieties that can produce high yields under conditions of non-pesticidal (fungicides, herbicides) technologies. The introduction of varieties with increased resistance to diseases is also advisable in order to prevent wastewater pollution with pesticides and chemicals. In the field of rice production, certain successes have already been achieved in developing and introducing into the industrial production of domestic rice varieties with pyramided genes of resistance to blast [6-8].

Genes determining broad-spectrum resistance which are an important genetic resource for breeding were identified in rice. These include genes Pi-1, Pi-2, Pi-33 (Deng Y., et al., 2006). For example, the C101A51 line carrying the Pi-2 gene was unsusceptible when tested with 455 M. grisea isolates in the Philippines; in phytopathological studies in 16 countries, it also showed a wide range of pathogen
resistance (Chen D.H., et al., 1996). When the C101A51 line was infected with pathogen strains from
the main rice-growing provinces of Central and Southern China, only 7.55% of the 792 isolates used
showed a compatible reaction with plants. Of particular interest to the scientific community at present
is the relatively recently identified rice resistance gene Pi-40, which is resistant to a wide range of
blast races (Jeung J.U., et al., 2007.). However, most genes for resistance to blast in rice determine
plant immunity with a limited number of pathogen races. Numerous studies show that such genes
during pyramiding (joint action) in one genotype can provide the greatest effect in stable resistance to
disease (Girish Kumar K., et al., 2000; Correa-Victoria F.J., et al., 2003). At present time a number of
successful foreign breeding programs have been carried out to develop rice varieties resistant to blast
by the method of gene pyramiding (Oka H.I., et al., 1957; Nakajima T., et al., 1996; Wang Z.X., et al.,
1999; Girish Kumar K., et al., 2000; Tabien R.E., et al., 2000; Conaway-Bormans C.A., et al., 2003;
Coca M.C., et al., 2004; Choi H.C., et al., 2006; Jeung J.U., et al., 2007; Wiltcombe J.R., et al., 2007).
The efficiency of the Pi-I gene in manifesting resistance when combining it with the Pi-2 gene in one
genotype of rice plants is especially noted.

Inefficient agricultural practices, intensification of food production contributed to the pollution of
the environment, natural ecosystems, ground and surface waters for many years, and led to a reduction
in biodiversity [9]. Due to the fact that it is impossible to eliminate all abiotic and biotic stresses, a
further increase in yield will be difficult to achieve without improving the genetic potential of the yield
of varieties.

Scientists concluded that the main scientific breakthroughs should occur in the basic physiology of
plants, ecophysics, agroecology and soil science in order to achieve environmental intensification,
which is necessary to meet the expected increase in rice production. To increase yield, along with
increasing adaptability and stress tolerance of varieties, emphasis was also placed on changing the
ideotype of rice plants, a new type with low tillering, a high number of grains per panicle — 200-250
pieces, plant height 90-100 cm, thick and strong leaves and stem, dark green and erect, with a duration
of plant growth of 100-130 days and an increased harvest index was proposed [10].

The results showed that there is a huge amount of “hidden” diversity of abiotic and biotic stress
tolerance in the primary rice gene pool. Using genomic tools, it is possible to provide a unique
platform of breeding materials for developing new modern varieties with an enriched pedigree [11].

In a number of countries, the concept of modern rice breeding to improve the quality of milled rice
and achieve sustainable production has recently become ecological super-rice (GSR), defined as a rice
variety that can produce high and stable yields with fewer resources (water, nutrients, pesticides ) and
in adverse environmental conditions. Breeding varieties with higher Nutrient use efficiency — NuUE
is necessary not only to increase productivity, but also to reduce production costs, as well as to avoid
environmental pollution and support the sustainability of the farming system. To improve such
complex characteristics of grain crops as stress resistance to biotic and abiotic factors, they use the
rich genetic diversity of the crop, which in the World Rice Germplasm Collections has been the
driving force for improving rice quality in the past, and will be so in the future. Marker assisted
selection (MAS) has been used very successfully to improve highly inherited traits such as disease and
insect resistance [12].

Along with attracting valuable sources and donors of germplasm to the breeding process, scientific
tasks have been set in realizing the genetic mechanisms of the plants long-term resistance to fungal
pathogens, since the increase in the blast epiphytotes is observed in all rice-growing regions of the
world. Currently, fungicidal treatments are used in 90% of the rice-growing territory of Russian
Federation and 70% in China. In the current situation, it is impossible to talk about the ecological
recovery of rice-growing regions and environmentally friendly rice-growing products. At the same
time, rice production remains an important strategic direction for the development and recovery of the
economy of Krasnodar region, the main rice growing region of Russian Federation, and in China it is
the main national strategic grain crop.

The purpose of this research is to develop an innovative breeding algorithm for developing rice
varieties with long-term resistance to fungal parasite based on an integrated approach that combines
classic breeding with postgenomic cell technologies for environmentally friendly pesticide-free farming.

2. Methodic of experiment
As a material for research, we used the achievements of modern Russian and Chinese national breeding — 68 varieties and lines with field and raspecific specific resistance to blast from the gene pool of ARRRI collection. When implementing the experiment in 2018-2019 we used modern methods of phenotyping, genotyping, phytopathological assessment, as well as experimental haploidy. To develop homozygous lines (DH lines), the anther culture method in vitro was used. When working, the sterility rules developed for the cultivation of cells and tissues were observed [13,14]. Field studies were conducted in the collection nursery of the experimental irrigated plot of All-Russian Rice Research Institute (Krasnodar), laboratory experiments were conducted in the conditions of the laboratory of biotechnology and molecular biology, unique scientific unit “Collection of rice genetic resources, vegetables and melons” and the hybridization group of breeding department. For genotyping we used markers associated with genes controlling resistance to pathogens: marker k8823 (Pi-k gene localized on chromosome 11 of Pi-k SNP); marker pB8 (Pi-9 gene located on the 6th Pi-9 chromosome); PCR analysis was performed using kits manufactured by SibEnzyme LLC (Russia); PCR visualization of the product was carried out by electrophoretic separation of DNA fragments. During electrophoresis, DNA fragments migrate in a 2.5% agarose gel based on 0.5×Tris borate buffer under the influence of electric field forces. The results of DNA electrophoresis in agarose gel were recorded in the presence of ethidium bromide- intercalating compound, which forms a stable compound with DNA fragments, which appears in ultraviolet light at 290-330 nm in the form of luminous bands.

Phytopathological evaluation of rice samples for resistance to the blast pathogen P. oryzae was carried out according to the methodology of the All-Russian Research Institute of Phytopathology (Moscow) against a provocative background of the infectious nursery of the laboratory of agriculture. From an international set of differentiating varieties (China, Japan, India, and the Philippines), 26 monogenic rice lines with known resistance genes were used to identify races of the blast agent: Pi-1, Pi-3, Pi-9, Pi-t, Pi-ta, Pi-ta2, Pi-a, Pi -b, Pi-i, Pi-19, Pi-20, Pi-40, Pi-k, Pi-kh, Pi-kp, Pi-ks, Pi-km, Pi-sh, Pi-z, Pi-z5, Pi-zt, Pi-5(t), Pi-7(t), Pi-11(t), Pi-12(t).

The affection of plants with the leaf form of blast was noted 10 and 20 days after inoculation, and the neck and panicle forms were noted in the phase of milk-wax and full ripeness of grain. Two indicators were taken into account: the type of reaction (in points) and the intensity of plant damage (in%). The stability of rice varieties was determined by the damage to leaves, nodes, stems and panicles, and the disease development index (DDI, %) was evaluated.

3. Results of research
Assessment of immunity revealed rice forms from ARRRI collection resistant to the blast pathogen, adapted by the rate of plant development to the weather and climatic conditions of Krasnodar region.

Table 1 presents Russian varieties from the number cultivated in Krasnodar region with a high yield potential, the desired morphotype and varieties of Chinese breeding adapted to the environmental conditions of the Kuban in terms of plant development rate and resistance to the local race of blast pathogen.

Based on phenotypic data, parental maternal forms were selected from number of rice varieties of local breeding: Flagman, Leader, Rapan, Atlant, Sonnet, Sonata, Krepysh, Privolny, Kurazh. The breeding process with the domestic germplasm includes the Chinese breeding lines Hejiang 20, Dongnong 416, Liaoqing 168, Liao0xing 21, HY 11, Liaoxing 401, Liaoakai 79, Pi9-177, resistant to disease and carrying resistance genes (Pi-b, Pi-ta, Pi-tr, Pi-gy8, Pi-9).
Table 1. Characteristic of initial forms of Russian and Chinese breeding selected for hybridization programs

| Number in the catalogue | Name          | Originator, country | Disease development index (DDI), % |
|-------------------------|---------------|---------------------|----------------------------------|
| 1                       | 04062 Rapan   | ARRRI, Russia       | 45.0                             |
| 2                       | 04074 Leader  | ARRRI, Russia       | 23.3                             |
| 3                       | 04197 Atlant  | ARRRI, Russia       | 25.0                             |
| 4                       | 04220 Sonet   | ARRRI, Russia       | 32.0                             |
| 5                       | 04222 Sonata  | ARRRI, Russia       | 22.2                             |
| 6                       | 04335 Flagman | ARRRI, Russia       | 35.0                             |
| 7                       | 04666 Krepysh | ARRRI, Russia       | 38.0                             |
| 8                       | 04667 Privolny 4 | ARRRI, Russia | 22.0                             |
| 9                       | 04670 Kurazh  | ARRRI, Russia       | 33.5                             |
| 10                      | 04207 Deshan B | China              | 5.6                              |
| 11                      | 04649 Mi 07-980 | China          | 18.9                             |
| 12                      | 04650 Mi 07-1055 | China          | 15.6                             |
| 13                      | 04683 175-3-09 Long ting 18 | China | 6.7                              |
| 14                      | 04688 175-2-09 Long Ting 16 | China | 16.7                             |
| 15                      | 04689 175-1-09 Long ting 15 | China | 5.6                              |
| 16                      | 04692 170-2-09 Long Ting 12 | China | 11.1                             |
| 17                      | 04693 180-3-09 Mu 07-1111 | China | 17.5                             |
| 18                      | 04694 180-2-09 Mu 07-1049 | China | 15.6                             |
| 19                      | 04695 175-5-09 Long Ting 20 | China | 18.9                             |
| 20                      | 04698 170-3-09 Long Ting 13 | China | 15.6                             |
| 21                      | 93-133 Dong-415 | China            | 27.4                             |
| 22                      | 03-99 Deshan B | China              | 33.0                             |
| 23                      | 04-38 Csing Feng 2 | China          | 23.7                             |
| 24                      | 253-05 Dong Nong v7 | China      | 30.0                             |
| 25                      | 255-05 Dong Nong 418 | China      | 31.0                             |
| 26                      | 244-06 Xieyov  | China              | 32.0                             |
| 27                      | 245-06 Zhongyong ZH3 | China | 26.7                             |
| 28                      | 247-06 Qianyon 1 | China            | 24.5                             |
| 29                      | 84-07 XIAOMA CU (ACL 56158) | China | 23.8                             |
| 30                      | 235-09 Tong Jing 29 | China      | 18.0                             |
| 31                      | 236-09 Chang Bai | China            | 22.2                             |
| 32                      | 546-10 611 B   | China              | 23.0                             |
| 33                      | 549-10 G 46 B  | China              | 24.8                             |
| 34                      | 552-10 933 B  | China              | 25.0                             |
| 35                      | 91-11 IRIS 251-53324 | China | 17.8                             |
| 36                      | 96-11 IRIS 251-53325 Takanari | China | 17.8                             |
| 37                      | 99-11 39B / Gisa 178 | China    | 20.3                             |
| 38                      | 107-11 Lider / TAKANARI | China   | 18.0                             |
| 39                      | 108-11 Lider / TAKANARI -2 | China | 16.8                             |
| 40                      | 246-11 ZAOXIAN 14 | China            | 30.0                             |
| 41                      | standard Avangard | Russia         | 8.9                              |

From the Chinese germplasm phytopathological assessment distinguished the following varieties: Deshan B, Mu 07-980, Mu 07-1111, Long ting 15, Long ting 18, Long ting 12, Long ting 13, Long ting 20, XIAOMA CU (ACL 56158), IRIS 251-53324, Takanari, 39B/ Gisa178, which showed a stable type of reaction and had a disease development index of less than 20.0%. These initial forms
represent a valuable pre-breeding resource for developing of varieties with pyramided genes of resistance to *Pyricularia oryzae* for the countries of Russia and China under the program of international cooperation.

The responsiveness of the studied genotypes of domestic breeding with target genes of resistance to blast to another culture *in vitro* was determined. Morphogenic callus lines were obtained, and genetically stable *DH lines* with high morphological and genetic alignment were developed using experimental haploidy on the basis of breeding-valuable samples that have given characteristics and carry genes with a wide spectrum of resistance to blast, as well as samples with race-specific resistance to the pathogen.

4. Discussion

Modern problems of agricultural production related to the vulnerability of varieties to diseases, climate change and other environmental stresses cannot be solved without the sustainable use of plant genetic resources. The most promising work is to include ecologically distant sources and donors of immunity, resistance to abiotic factors, productivity and quality into crosses. At the same time, it becomes important to identify the structure of genetic diversity in collections, and to conduct physiological and genetic assessments. Unlike breeding for economic traits, breeding for immunity requires knowledge of two organisms: the host and the pathogen, the system of their interaction in various agroecological conditions, as well as the genetic mechanism of resistance.

The selection of disease-resistant parent forms for breeding programs depends on the environmental conditions of the Kuban and the genetic structure of the *P. oryzae* fungus population. [15]. In this regard, the methods of evaluating and selecting starting material were differentiated: they used phenotyping in vivo of field experiment and provocative background, as well as the DNA genotyping method to identify resistance genes. Molecular genetic methods identified genes controlling resistance to blast in 68 rice varieties. Of these, 28 donors of the *Pi-k* gene and 17 donors of the *Pi-9* gene were selected for breeding programs. It was established that the long-term resistance of rice varieties to blast cannot be ensured by the presence of a single gene of race-specific resistance. So, domestic genotypes with race-specific resistance (with *Pi-b*, *Pi-ta*, *Pi-z* genes) Talisman and Snezhinka stably showed resistance to pyriculariosis. Monogenic lines and differentiator varieties of blast races, when tested in 2018 against a provocative background (field experiment), showed the degree of infection within the DDI: 10.5 - 40.0%. The standard susceptible variety Pobeda 65 showed a significant degree of damage with pathogen — 68.9%. A phytopathological assessment of 26 monogenic indicator lines showed that resistance to the Krasnodar pathogen population in 2018 was shown by forms with genes: *Pi-zt, Pi-a, Pi-k, Pi-1, Pi-z5, Pi-ta, Pi-7 (t), Pi-5 (t), Pi-11t, Pi-9, Pi-3, Pi-19, Pi-21, Pi-40* [16].

The study clearly demonstrated the effectiveness of the combination of phenotyping and DNA genotyping for the selection and improvement of starting material in rice breeding for immunity. A system for assessing the effectiveness of genes for a local pathogen population using an international set of standards — carriers of resistance genes allows us to develop a further strategy for large-scale screening of the gene pool for immunity and to identify a number of genes for breeding improvement of rice genetic resources: *Pi-1, Pi-z, Pi-a, Pi-9, Pi-ta.*

The transition to a new breeding paradigm based on the use of the so-called postgenomic technologies and the genomic approach significantly affects the pace and quality of the breeding process. The breeding scheme includes a series of backcrosses for the transmission of donor traits (resistance to a wide range of blast races, race specific parasite resistance) to recipient forms, which are elite varieties of Russian and Chinese breeding. As a result of donor crosses between donors of effective genes of race-specific blast resistance of Chinese breeding and domestic germplasm, a collection of initial forms with target resistance genes is formed. At the next stage of the experiment on developing breeding valuable samples, marker control of the results of backcrossing of resistance genes was applied. In vitro anther culture method was used to obtain genetically stable (homozygous) rice forms based on newly developed breeding-valuable forms and to accelerate the breeding process.
Optimization of the technology for developing sustainable rice varieties involves their phenotyping according to the studied trait (resistance to local blast populations) in the territories of two countries - Russia and China. As well as an assessment of the variety identified according to phenotyping data on a complex of economically valuable traits.

5. Conclusions
In the process of research, phenotyping of the intraspecific diversity of the *Oryza sativa* L. collection was carried out according to a number of breeding valuable traits, which made it possible to identify their wide polymorphism and to highlight promising starting material (sources and donors) for solving urgent problems of domestic breeding. For the first time in rice crop, a database has been created where traditional methods for characterizing collection samples are supplemented by molecular genotyping of the diversity of European and Asian ecological and geographical groups. According to the results of studies from a set of varieties, a group of collection samples with identified genes that control resistance to blast is formed. The method of another culture *in vitro* produced doubled rice haploids, the use of which will intensify breeding of this cereal crop in Krasnodar region, reduce the time of developing varieties with target genes and increase the efficiency of domestic rice growing.

Acknowledgement
This work was supported by the RFBR fund for an international project № 19-516-53001 GFEN_a “Development and use of rice pre-breeding resources with pyramided genes with broad spectrum resistance to blast agent”.

References
[1] Zelenskiy G L, Zelenskiy A G, Romashchenko T A and Stukalova V A 2015 Breeding rice varieties for environment-friendly technologies *Proc. Int. Conf. Achievements and development prospects of rice breeding and cultivation in temperate countries* Nov 26-27 (Krasnodar) ed S V Garkusha, E R Avakyan, V S Kovalyov and E V Dubina (Krasnodar: All-Russian Rice Research Institute Publ) pp 256-261
[2] Zelenskiy G L, Chebotarev M I, Logoyda T V, Zelenskaya O V and Salay A V 2018 *Proc. Kuban State Agrarian Univ.* 74 53 (In Russ)
[3] Zelenskiy G L, Tumanyan N G, Zelenskiy A G, Maksimenko E P, Romaschenko T A and Tsogoeva V V 2016 *Risovodstvo* (Rice growing) (1-2)(30-31) 6 (In Russ)
[4] Zilhas A J, Jauhar A, Yunlong Pang, Anumalla M and Zhikang Li 2019 *The Crop J.* 7(3) 368
[5] Tuong T P, Bouman B A M 2003 Rice production in water scarce environments *Water Productivity in Agriculture ser Limits and Opportunities for Improvement Comprehensive Assessment of Water Management in Agriculture* ed J W Kijne, R Barker and D J Molden (Wallingford: CAB Int Publ) pp 53-68
[6] Shilovsiy V N, Suprun I I and Ogly A M 2016 *Grain economy of Russia* 5 29 (In Russ)
[7] Zelenskiy G L and Zelenskiy A G 2018 *Agrarny Vestnik Yugo-Vostoka* (Agrarian Reporter South-East) (3)(20) 15 (In Russ)
[8] Suprun I I, Kovalev V S, Kharchenko E S and Savenko E G 2016 *Vavilov J. Genetics Breed.* 20 333
[9] Cassman K G 1999 *Proc. Nat. Acad. Sci. USA* 96 5952
[10] Peng S, Khush G S, Virk P, Tang Q and Zou Y 2008 *Field Crop Res.* 108 32
[11] Ali A J et al 2006 *Field Crops Res.* 97(1) 66
[12] Zhi-Kang Li and Fan Zhang 2013 *Current Opinion in Plant Biology* 16 261
[13] Savenko E G, Suprun I I, Glazyrina V A and Shundrina L A 2016 *Subtrop. Decorat. Garden.* 58 106
[14] Savenko E G, Mukhina Zh M, Glazyrina V A and Korotenko T L 2019 Development of homozygous rice lines with genes of resistance to blast using experimental haploidy *Proc. Int. Conf. Science Production, Business: Current State and Ways of Innovative Development*
of the Agricultural Sector by the Example of Bayserke-Agro Agricultural Holding Apr 4-5 ed B T Zhumalov et al vol 2 (Almaty, Kazakhstan) pp 54-58

[15] Korotenko T L, Bragina O A, Suprun I I, Makhina Zh M, Epifanovich Yu V, Petrukhnenko A A and Khorina T A 2018 Vavilov J. Genetics Breed. 22 69

[16] Korotenko T L, Makhina Zh M and Savenko E G 2019 Resistance to blast of rice varieties of Russian and Kazakh breeding from ARRRI collection under environmental conditions of Kuban Proc. Int. Conf. Science Production, Business: Current State and Ways of Innovative Development of the Agricultural Sector by the Example of Bayserke-Agro Agricultural Holding Apr 4-5ed by B T Zhumalov et al vol 1 (Almaty, Kazakhstan) pp 319-324